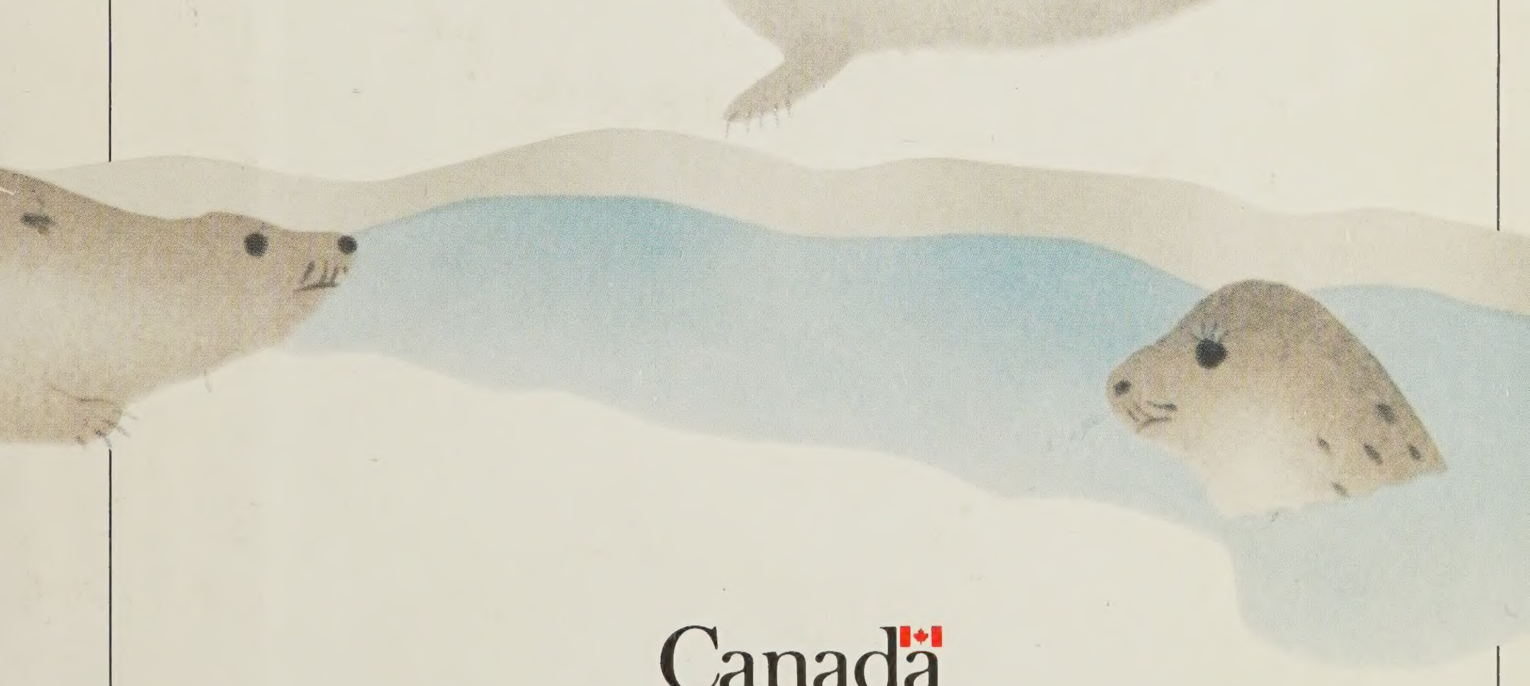
Seals and Sealing in Canada

Report
of the Royal Commission

Volume 3



Canada

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ROYAL COMMISSION

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Chapter 20

Methods of Killing Seals

As with all slaughter operations, mistakes are made; the system breaks down. I would say it breaks down less at the seal hunt than it does in the majority of our slaughter operations in Canada (Quine, 1985).

Introduction

World-wide, 15 species of seals and sea lions are now killed each year or have been killed until very recently. (See Table 20.1.) These animals are killed in commercial and susbsistence hunts to obtain various seal products, and in bounty programs and organized hunts that are intended to control seal numbers. Although shooting is the most common method of killing the various species of seals, the major commercial seal hunts most generally use clubbing as the means of killing. In some areas seals are also taken in nets; they are harpooned in some subsistence hunts, and they are killed by drug injection in one commercial harvest.

One of the major grounds of objection to the hunting of seals, and particularly of harp seal pups, has been the alleged cruelty of the operations. These allegations have made it necessary for the Royal Commission to examine the issue carefully, and to try to determine how far they are justified. In carrying out these tasks the Royal Commission has considered not only the killing of harp seal pups, but also the killing of all seals under Canadian jurisdiction and killing of seals in other countries.

From one point of view, the killing of any animal by any means can be considered an act of supreme cruelty. Such a view is one aspect of the basic question of humanity's relationship to other animals, and the Royal Commission has considered this matter at length in Chapters 8 and 12. In the present chapter, the concern is with the manner in which the animals are killed, once it has been decided that they are to be killed. The task, therefore, is to examine and describe the methods by which seals are killed in Canada and in other countries, as well as the circumstances under which the killings take place, and to try to draw conclusions about the extent to which the various killing operations can be fittingly described as "humane". It is

Table 20.1
Methods of Killing Seals

Species	Location	Annual Kill[a]	Killing Method[b]	References
Steller sea lion *(Eumetopias jubatus)*	Alaska	3	S?	Mate (1982)
	Japan	1	S?	Mate and Gentry (1979)
	U.S.S.R	?	S?	Mineev (1975)
South American sea lion *(Otaria flavescens)*	Uruguay	3	C	Vaz-Ferreira (1979a, 1982)
	Chile	2–4	?	FAO (1984)
	Peru	3	C	Vaz-Ferreira (1982)
Northern fur seal *(Callorhinus ursinus)*	Alaska	5	C	Keyes (1980), NPFSC (1983)
	U.S.S.R.	4	C	U.S.S.R. (1980), NPFSC (1983)
South American fur seal *(Arctocephalus australis)*	Uruguay	4	?	Vaz-Ferreira (1979b),
	Chile	2	?	FAO (1984), FAO (1982)
Cape fur seal *(Arctocephalus pusillus)*	South Africa	5	C	Shaughnessy (1976)
	& Namibia	3	S	King (1983)
Harbour seal *(Phoca vitulina)*	Canada	2[c]	S	Boulva (1973), Bonner (1979a)
	Greenland	1	?	Kapel (1975)
	Iceland	3	C, N	Einarsson (1978), Bonner (1979a)
	United Kingdom	2[c]	S	Bonner (1979a, 1982)
	Norway	?[c]	S?	Øritsland (1985)
	U.S.S.R.	?	?	Bychkov (1971)
	Japan	2	S, N	Naito (1971)
	Alaska	4	S?	Bonner (1979a)
Larga seal *(Phoca largha)*	U.S.S.R.	4	S	Marakov (1967), Popov (1982)
	Japan	1	S, N	Naito (1971)
	Alaska	3	S?	Bonner (1979b)
Ringed seal *(Phoca hispida)*	Canada	5	S, N	Davis et al. (1980), Canada, DFO (1985)
	Greenland	5	S, N, H	Kapel (1975, 1981)
	Finland	1	S?	Almkvist (1981)
	U.S.S.R	5	S?	Popov (1982)
	Japan	1	S, N	Naito (1971)
	Alaska	4	S	Stirling and Calvert (1979)
Baikal seal *(Phoca sibirica)*	U.S.S.R.	3	S, N	Mineev (1971), Popov (1982)
Caspian seal *(Phoca caspica)*	U.S.S.R.	5	C?	Badamshin (1960), Popov (1979, 1982)

Table 20.1
Methods of Killing Seals (continued)

Species	Location	Annual Kill[a]	Killing Method[b]	References
Harp seal	Gulf (Canada)	5	C, S, N	Reeves (1977), Lavigne (1979)
(Phoca groenlandica)	Front (Canada, Norway)	5	C, S, N	Reeves (1977), Lavigne (1979)
	Arctic Canada	3	S, N	Davis et al. (1980), Canada, DFO (1985)
	Greenland	3–4	S, N, H	Kapel (1975, 1981)
	Jan Mayen (Norway)	4	C?, S?	Lavigne (1979)
	Barents Sea (Norway)	4	C?, S?	Lavigne (1979)
	White Sea	3	C	Barzdo (1980)
	(U.S.S.R.)	4	D	Barzdo (1980)
		?	N?	Sdobnikov (1933)
Ribbon seal	U.S.S.R.	3	S	Shustov (1965), Popov (1982)
(Phoca fasciata)	Japan	2	S, N	Naito (1971)
	Alaska	2	S?	Stirling (1979)
Bearded seal *(Erignathus barbatus)*	Canada	3	S	Davis et al. (1980), Canada, DFO (1985)
	Greenland	2	S, N, H	Kapel (1975, 1981)
	U.S.S.R.	4	S?	Popov (1982)
	Japan	1	S, N	Naito (1971)
	Alaska	3–4	S	Burns (1967), Stirling and Archibald (1979)
Hooded seal *(Cystophora cristata)*	Front (Canada, Norway)	4	C, S	Rowsell (1975), Sergeant (1979)
	Greenland	3	S	Kapel (1975, 1981)
	Jan Mayen (Norway)	5	C?, S?	Sergeant (1979)
Grey seal *(Halichoerus grypus)*	Canada	2–3[c]	C, S	Hoek (1985), Canada, DFO (1985)
	Iceland	2	C, N	Einarsson (1978), Bonner (1979c)
	Faeroe Islands	?	S?	Bonner (1979c)
	United Kingdom	3	S	Bonner (1982)
	Norway	?[c]	S?	Øritsland (1985)
	Finland	1	S?	Almkvist (1981)

a. Approximate annnual catches at 1982 or earlier levels.
1 = 1 to 249; 2 = 250 to 1499; 3 = 1500 to 7499; 4 = 7500 to 24,999; 5 = 25,000 or more.

b. C = clubbing; D = drug injection; H = harpoon; N = Nets; S = shooting.

c. In part or in whole a cull or bounty operation to control the population.

also to consider whether the procedures now in use could or should be modified or replaced by methods which would be more humane.

Generally speaking, there is no such thing as an absolutely humane or an absolutely cruel way of killing an animal. All procedures will lie somewhere within a spectrum which, at least theoretically, has no limits. For this reason, the aim in any killing operation should be to move as far as possible towards the humane end of the spectrum.

Finally, this chapter compares the killing of seals with two other activities in which humans kill very large numbers of mammals. These are slaughtering in abattoirs and big game hunting. The purpose of these comparisons is not to determine whether the killing of seals is absolutely humane, but to find out where the seal-killing operations lie within the humaneness-cruelty spectrum as compared to these other major killing operations which are accepted, albeit implicitly, by many members of the public.

Criteria of Humane Killing

The definition of humane killing developed by the Canadian Federation of Humane Societies and adopted by the Committee on Seals and Sealing (COSS) states:

> *A humane death is that in which the animal suffers neither panic nor pain. In practice, this may be achieved by instantaneous death or immediately rendering the animal unconscious with early and inevitable subsidence into death without the regaining of consciousness (COSS, 1978).*

This definition can be viewed as representing the highest achievable point at the humane end of the spectrum denoted above.

There are three main issues to consider in discussing humane killing: pain, stress in the animal about to be killed, and stress in other animals present. The American Veterinary Medical Association (AVMA) Panel on Euthanasia contains the following information about pain:

> *The sensation of pain is initiated by damage to or intense stimulation of almost any part of the body. In tissues, pain receptors react to substances released when tissue is damaged . . .*
>
> *Recognition of pain by an animal depends on impulses from pain receptors traversing pain pathways leading to the thalamus and cerebral cortex. For pain to be experienced, the cerebral cortex and subcortical structures must be functional. An unconscious animal does not experience pain because the cerebral cortex is not functioning. If the cerebral cortex is rendered nonfunctional by any means such as hypoxia, depression by drugs, electric shock, or concussion, pain is not experienced.*
>
> *In an unconscious animal, stimuli that evoke pain will elicit reflex responses manifested by motor movements. For this reason, purposeful or nonpurposeful movements of an animal are not reliable indicators of cerebral pain reception (AVMA, 1978).*

The goal of promoters of humane killing is to produce a method of killing in which, as a first step, the animal is brought as quickly as possible to a state of unconsciousness and insensitivity to pain. As a second step, the method should lead fairly quickly to the death of the animal before it has regained consciousness. Humane killing techniques usually consist of two separate steps taken to meet these two requirements, but in some techniques a single step may sometimes or invariably cause death.

The other important considerations in humane killing are to eliminate, as far as possible, the stress and panic the animal undergoes prior to being killed, and to avoid, as far as possible, stress experienced by any other animals that are in the immediate vicinity and are aware of the killing.

Methods of Killing Seals

As Table 20.1 shows, the three principal methods of killing seals are:

- Clubbing. This method is widely used to kill harp and hooded seal pups, and to kill northern fur seals.

- Shooting. This method is used extensively in Canada in the hunt for hooded and older harp seals. It is the principal method of killing seals in the Arctic and is used in most culling operations aimed at controlling seal numbers.

- Netting. This method has been used locally in Canada in the harp and other seal hunts.

Some other methods which are, or have been, in use among the aboriginal peoples of the Arctic or in other countries are also described in this chapter.

Finally, consideration is given to a number of other possible methods of killing seals, successful or unsuccessful, which have been proposed with the intent of increasing the humaneness of the hunt.

Clubbing Seals

Of all the methods of killing seals, clubbing – in particular, the clubbing of whitecoat harp seals – has been much the most controversial. Many qualified observers have considered clubbing a humane method of killing seals; others have disputed that opinion. Whether or not clubbing is humane, it presents a brutal image, and the image of a sealer clubbing a baby seal has been a major factor in the arguments about the Canadian harp seal hunt. (See Chapter 9.)

Seals are clubbed on land or on ice, where they can move only awkwardly and thus cannot avoid the club. When the method is conducted properly, the sealer strikes the seal on the head with enough force to produce rapid unconsciousness (or sometimes death) either by skull fracture or by hemorrhaging within the brain. The sealer then ensures the death of the seal from exsanguination (bleeding), either by cutting major arteries or by piercing its heart.

Clubbing is used as a method of killing seals in or by Canada, Norway, the United States, the U.S.S.R., Uruguay, South Africa, Namibia and Iceland.

Harp and Hooded Seals

In the Canadian hunt, harp and hooded seals are clubbed on the ice within a few weeks of birth, before they will willingly enter the water. The

sealer who follows the desirable procedure for humane killing strikes the seal enough blows on the top of the head to produce unconsciousness. Although a single blow may produce unconsciousness (Rowsell, 1973), the law now requires that the sealer strike sufficient blows to crush the seal's skull. The sealer then checks to ensure that the seal is unconscious before turning the animal over, cutting it open along the midline, and bleeding it, usually by severing the arteries to the forelimbs. The seal's death rapidly follows. Once the seal has been bled, it is skinned (a process more properly termed "flensed" as the fat is removed with the pelt).

Government Regulations on Killing Methods

Although clubbing has always been the main method of kill used in the seal hunt, it was not until 1964 and 1966, when the nature of the sealing operations had begun to attract public attention, that regulations controlling the killing of harp and hooded seals were first introduced; the regulations have been frequently amended since. Many of the amendments derived from recommendations made by veterinarians and other qualified persons who had observed the hunt in behalf of animal-welfare organizations, under the auspices of the Committee on Seals and Sealing (COSS), or in behalf of the government. A chronological review of the changes made to the Canadian Seal Protection Regulations is provided in Chapter 30 from a brief published by the Department of Fisheries and Oceans (Canada, DFO, 1985), and copies of the various regulations and amendments are contained in Appendix XIX of that brief. The principal changes in the regulations since 1964 are reviewed in Appendix 20.1.

The regulations now in force and their dates of introduction include the following:

- gaffs are prohibited for killing seals (1967);
- hakapiks are permitted (Front, 1976; Gulf, 1979);
- hooded seals that are shot must also be clubbed (1977);
- a seal must be struck until its skull is crushed (1984);
- a seal must be dead before being skinned (1964);
- criteria of death are defined (1978);

- a seal must be bled immediately after clubbing (1979);

- use of aircraft to hunt is prohibited (1964; 1970);

- night sealing is prohibited (1967);

- sealers are licensed and power is conferred on fisheries officers to suspend licences (1966; 1967);

- criteria are established for experienced and assistant sealers (1978).

Under the current regulations, seals are clubbed either with a hakapik or with a club. The regulations define these instruments in detail. The hakapik has an iron head mounted on a wooden handle which is 42–60 inches long and 1 1/4–2 inches in diameter. On one side of the iron head is a spike less than 5 1/2 inches long that curves slightly towards the handle. On the other side there is a blunt projection less than 1/2 inch long. The club is a hardwood bat 2–2 1/2 feet long and at least 2 inches in diameter for at least half its length. No metal hook is attached to the club.

The Norwegian sealing regulations that relate to killing methods as of 1968 and 1970 are summarized in Appendix 20.2.

Government Enforcement and Training Programs

When, in 1964, the Government of Canada implemented its humane killing requirements in the Seal Protection Regulations, it also undertook an enforcement program. Since that time fisheries officers have patrolled the seal hunt by using helicopters or by sailing on sealing vessels. Their duties have involved checking licences; examining killing weapons and observing killing techniques; checking to see whether the seal's skull is fractured; and performing other tasks unrelated to humane killing. Fisheries officers have the power to suspend a licence and to order a sealer from the ice, or to lay charges when they observe contraventions of the regulations. The usual practice has been to suspend licences. In 1979, for example, 19 licences of landsmen from the Magdalen Islands were suspended for resorting to improper killing methods (Dudka, 1979).

Still, the number of fisheries officers assigned to the seal hunt is limited: there were 89, for example, in 1979 (Montreuil, 1980). In addition, the area that they must patrol is very extensive, the number of sealers is large,

and sealing operations are multifaceted. For these reasons it is impossible to keep all parts of the seal hunt under close supervision at all times.

Many people who have observed the seal hunt to assess its humaneness have commented on the government's efforts to enforce its regulations. The Royal Commission has seen reports from only two observers (Simpson, 1966, 1967a; Jordan 1978, 1985) who considered that the hunt could not be patrolled effectively enough to make it acceptable. The opinions of the other observers have varied greatly, since they have depended on the year and area of their observations. In the mid- to late 1960s, most observers were impressed by the government's efforts to control the seal hunt and by the improvements that they noted each successive year (e.g., Hughes, 1966, 1967, 1968). In other years, the same observers (e.g., Hughes, 1971) have sometimes considered that enforcement efforts should be stepped up. Enforcement has been criticized most severely in years when the fisheries officers could not keep landsmen hunts under control, particularly in 1981 off Prince Edward Island (e.g., Platt, 1981). The next year, however, praise for the enforcement officers was expressed again (Hughes, 1982; Platt, 1982).

Government training programs also form an important part of the effort to promote humane killing practices. Early observers of the seal hunt urged strongly that sealers receive instruction in humane killing methods (Pimlott and Hardy, 1966; Scollard and Hughes, 1966; MacLeod, 1967; St. Onge, 1967; Walsh, 1967; Hughes, 1971). Informal instruction in humane killing was begun in the Magdalen Islands in the early 1970s (Canada, DFO, 1985). In 1975, instructions that included a demonstration were given at eight sites to more than 400 sealers (Ronald, 1975). An educational program that included humane killing was offered more actively in Newfoundland in 1978 (Collins and Curran, 1978). In 1979, the topic of humane killing was covered at a meeting in St. John's attended by all sealers from large vessels (Rowsell, 1979a). In 1980, fisheries officers gave training symposia at each Newfoundland sealing community (Canada, DFO, 1985).

To supplement this instruction, the federal government has also produced publications and pamphlets on humane killing of seals. The 1978 and 1979 pamphlets (as reproduced in Rowsell, 1978 and CVMA, 1979) emphasize the need to strike at least three blows with a club or hakapik, and the importance of ensuring that the seal is unconscious by checking its blinking reflexes. They say nothing about the need for rapid exsanguination, but this topic was included in the 1981 sealer's manual (Canada, DFO, 1985, Appendix XX) and in a more recent brochure on humane killing (Canada, DFO, 1985, Appendix XV).

Observations of Clubbing at the Seal Hunt

Early Observations

Inhumane practices in the seal hunt were apparently common prior to the 1965 hunt, when the first government regulations to prevent such practices were put into force. England (1924) described his experiences on a large vessel in the Newfoundland seal hunt during 1922. As Watson (1985) has pointed out, England made a number of references to cruel and inhumane practices such as flensing a seal that had been clubbed and was not dead (p. 84) and hauling live seals in on gaffs (p. 87); he recorded that the captain had told a sealer to kill his seal and not to skin it alive (p. 87); he also mentioned that a very small whitecoat was stabbed and left dying, but not utilized (p. 91), that a sealer had kicked a seal in the head to stun it and then hauled it back to the ship (p. 184), and that hooded seals were wounded by inaccurate shooting (p. 230–231); he recorded, too, the loss of many seals that were shot (p. 230–231). Lillie (1955) visited the Front in 1949 and commented on particular instances of inhumane clubbing and shooting of seals, although in general he found the clubbing of seals to be humane.

Hunt in the Gulf, 1966–1968

Although public concern about inhumane killing practices grew considerably during the 1950s and early 1960s, few observations of the actual killing process date from that period. From 1965 to the present, at least 44 veterinarians, animal-welfare officers and biologists have made a minimum of 86 visits to the seal hunt to observe the clubbing of seals and to comment on its humaneness. The reports of these observers have been deposited with the DFO headquarters library in Ottawa and the Pinniped Bibliography at the University of Guelph.

Eight observers visited the harp seal hunt in the Gulf in 1966. They examined hundreds of skulls, most of which had been crushed, though some were undamaged. The observers could not judge whether the seals whose skulls remained intact had been struck unconscious prior to skinning (Hughes, 1966). Some blatant acts of cruelty were observed. In particular, nine seals were found which had been struck, but left bleeding and conscious, and 50 seals were found which had been slashed with a knife and had struggled for varying distances before they died (Hughes, 1966).

In spite of the observations of cruelty, all of the 1966 observers except Simpson (1966) were of the opinion that if the sealers were properly trained, and if the regulations were enforced more strongly and some changes made in them, the seal hunt could be made acceptably humane. Simpson held that although the club, if used properly, would produce instantaneous death with one blow, the conditions of the hunt and the inexperience of the sealers prevented them from making proper use of the club. She reported a number of instances of cruelty and concluded that she could not "envisage any way in which the commercial seal hunt in the Gulf of St. Lawrence could be made humane" and that "the seal hunt in the Gulf should be stopped."

In 1967, some observers reported a definite improvement in killing methods over those observed in 1966 (Hughes, 1967; Walsh, 1967). They did not observe any deliberate cruelty, and they recorded that the level of enforcement of the regulations had risen greatly. Walsh (1967) reported checking 512 skulls; 18 of these did not appear to have been fractured, three appeared to have been fractured only on the nose, and the rest evidently appeared to have been properly fractured.

In 1967, Simpson (1967a) noted some improvements in humane killing techniques, but she did not change her negative opinion of the overall acceptability of the hunt. She conducted post mortem examinations of 154 skulls, of which 98 had fractured crania (Simpson, 1967b). She concluded that "a large percentage of the hunted animals die in a manner which is of doubtful humanity."

Hughes (1968) reported a great improvement in the humaneness of the 1968 hunt over that of 1967. He found that seals killed by sealers from ships had uniformly been properly clubbed, and that the skulls found without massive damage were mainly in areas where airborne sealers had been working. He stated that:

> *As far as the killing of* young seals *is concerned, and in Area 2 of the Gulf... I am satisfied that we have now reached a standard of humane killing, acceptable to any reasonable person. (Emphasis in original.)*

Jones (1968) considered that "the methods of killing compared favourably with those of many slaughterhouses." Schiefer (1968a, 1968b) published the results of 695 autopsies of whitecoats performed by four veterinarians in 1968; 651 (93.7%) had skull fractures and/or brain hemorrhages and were

probably dead or unconscious before skinning, and another 1.7% were probably unconscious. It could not be determined whether the other 4.7% were unconscious at the time of skinning.

After observing the hunt, both Karstad (1970) and Ronald (1969) recommended that animals should be skinned or exsanguinated immediately after clubbing, but this recommendation was not made a requirement until 1979.

Overall, it appears that the humaneness of the killing procedures in the Gulf increased greatly between 1966 and 1968.

Hunt in the Gulf, post-1968

The Royal Commission has reviewed reports written by the observers of the post-1968 seal hunts in the Gulf of St. Lawrence that were conducted by sealers from large sealing vessels. The reports showed that with two exceptions, observers were generally satisfied with the humaneness of the clubbing they witnessed. One exception occurred in 1981, when Hughes (1981) observed a number of violations by the crew members of one large vessel, even though the crew was composed of the same sealers as in the previous year, when he had not observed any such violations.

The other exception occurred in 1978 and was reported by Jordan (1978), who visited the hunt in the Gulf in 1978 in behalf of the Royal Society for the Prevention of Cruelty to Animals (RSPCA). In one sample of 13 pups he examined, seven skulls had not been fractured. In two other samples all skulls were crushed, but some had been crushed after death. Of three pups he saw clubbed, one was still alive, with an unfractured skull, after having been clubbed, and in his report he raised a question as to whether it was unconscious when skinned. Following Jordan's report, the RSPCA strongly urged the Canadian government "to call an immediate halt to the killing of seal pups."

Sealers carried to the hunt by aircraft were not a concern in 1970 or afterward, as the use of aircraft in the hunt was prohibited in 1970 except for searching for seals.

Some of the most serious problems have arisen in hunts conducted by landsmen in the Gulf. These have occurred when ice conditions brought the whelping harp seals close to land, and there was a rush, often by inexperi-

enced men, to take part in the hunt. Enforcement of humane killing practices by fisheries officers in such hunts has been difficult and frequently not very effective because of the unpredictability of the time and location of such hunts, the numbers of landsmen who usually participated, and their inexperience. Violations of humane killing practices by landsmen from the Magdalen Islands were noted in 1971 (Hughes, 1971), 1974 (Terhune, 1974), 1975 (Ronald, 1975) and 1980 (Hughes, 1980). Fisheries officer Dudka (1979) reported a similar problem there in 1979. In 1974, a number of pups were found that had been killed and bled, but not skinned; an adult seal was found that had been wounded (presumably blinded), and six of 57 skulls were only partially crushed (Terhune, 1974). In 1975, several hundred landsmen "acted as if they had never been trained or instructed in killing techniques", and the chief fisheries officer threatened to recommend that the hunt be closed unless the inhumane and wasteful methods of killing were stopped (Ronald, 1975).

The most notorious problem with a hunt by landsmen occurred in 1981, when the seals whelped close to Prince Edward Island, a very infrequent occurrence. Because the landsmen had little sealing experience, several animal-welfare organizations recommended that the seal hunt should not be opened; nevertheless, it was allowed to commence. When the ice appeared, 240 sealers were given licences and a "crash course" on the sealing regulations (Platt, 1981). Still, Platt observed sealers clubbing seals and throwing them into a boat without exsanguinating them. CVMA (1981) reported an abandoned seal that had been killed, but not pelted; it was one-half metre from shore. Many other violations were observed, but fisheries officers were unable to control the sealers. Furthermore, much of the hunt was clearly visible to anyone on shore. The Department did react quickly, however, and after one day the hunt by landsmen was cancelled.

Canadian Hunt at the Front

Although many veterinarians, animal-welfare officers and biologists examined the seal hunt in the Gulf after 1965, no observers visited the Canadian seal hunt at the Front until 1972, when Rowsell (1972) made his first of many visits. He found that the club, as used in the Gulf, was not as effective as the hakapik for killing the larger harp seal pups on the Front or the hooded seal pups (Rowsell, 1975, 1977, 1980). He recommended that the hakapik be used (Rowsell, 1975), and its use was authorized on the Front in 1976. Rowsell (1975, 1976) also showed that hooded seal pups could be taken without shooting the female, and limits were placed on taking females in 1977.

For the most part, observers of sealers working at the Front from large vessels have been generally satisfied with the humaneness of the clubbing. Some violations of humane sealing practices were noted in 1978 (Jotham, 1978; Walsh, 1978).

The most serious problems noted at the Front occurred in 1981, when longliners were able to penetrate the ice and reach the whelping harp and hooded seals for the first time in at least nine years (Rowsell, 1981; Walsh, 1981). The vessels were poorly equipped for the hunt, and a number of the sealers apparently lacked knowledge of humane killing methods. Some sealers were clubbing seals with axe handles; some did not immediately exsanguinate and pelt their seals; and some were found to be taking hooded seals, though they did not have a quota for them.

Norwegian Hunt at the Front

In 1968 and 1970, observers were present on Norwegian sealing vessels at the Front in order to assess the humaneness of the crew's killing methods. Søgnen (1968) found that sealers used hakapiks rather than clubs, and all but one of the skulls he examined had one or more holes produced by the spike of the hakapik. Exsanguination often did not immediately follow the blows. The main reason for failure to kill seals efficiently was lack of training of young sealers; they quickly learned how to kill efficiently, but while learning they may have caused some unnecessary suffering. Søgnen concluded that the hakapik was an acceptable tool for killing, and that he could not find a better method for killing large numbers of seals under the conditions that prevailed.

Platt (1970) reported that the Norwegians had implemented most of Søgnen's recommendations. In contrast to the Canadian vessels at the Front, each of which had one or two fisheries officers aboard, the 15 Norwegian vessels carried only one fisheries officer for the entire fleet. The hunt was divided into three periods. During the first period, the Norwegians killed whitecoats with hakapiks. During the second period, beaters (seals at least four weeks old and capable of swimming) were shot or occasionally killed with hakapiks. During the last period, adults that had congregated in mating areas were shot on the ice. Platt's observations and conclusions generally paralleled Søgnen's. Although violations were observed, only a very few instances of unnecessary suffering were noted.

Rowsell observed Norwegian killing techniques in 1975 and 1980. In 1975, he examined approximately 50 harp seal skulls and found that all had

multiple skull fractures (Rowsell, 1975). Some sealers were using a heavy metal hook (slagkrok) about 50 centimetres long with a heavy bar in front of the hook. They would strike a seal two or three times with the bar and then drive the hook into the brain. Rowsell did not observe any skulls on which this technique had been used, but he considered that it should be used only on newborn pups. In 1980, he examined 25 skulls of seals that had been killed by Norwegians; all showed massive skull fractures and destruction of the brain (Rowsell, 1980).

Laboratory Studies of Clubbing

Only one laboratory study of the clubbing method of killing seals has been found (Blix and Øritsland, 1970). Three hooded seal pups were each given a single blow on the head with a Norwegian slagkrok. The single blow produced immediate irreversible disappearance of brain activity as recorded on an electroencephalogram (EEG). This result demonstrated that, at least under ideal conditions, such clubbing constituted a satisfactorily humane method of killing.

How Humane Is the Actual Killing?

None of the observers whose reports the Royal Commission has seen has disputed the fact that under good conditions, a sealer following the prescribed procedures can instantaneously kill a whitecoat harp seal or render it instantaneously unconscious with a proper blow of a club or hakapik. The requirement that the seal be exsanguinated immediately after clubbing ensures that the seal does not recover consciousness before death intervenes. The difficulties arise from the actual conditions under which the seal hunt is conducted.

The killing process that the regulations require and that if properly carried out will produce a death that is as humane as possible, consists of three steps: clubbing, testing the blink reflex, and exsanguination. Each of these steps, however, is subject to abuse.

Clubbing is a physical act, and the clubber must strike every blow with precision to ensure humane clubbing. It is probably impossible to invariably achieve this precision, given the cold and slippery conditions on the ice, the long hours, the pressure to work fast, and the possibility of a moving target. Some observers noted that sealers tend to become tired or to

develop tendonitis; they concluded that these factors influenced the sealers' clubbing (e.g., Jordan, 1978). Abuse of the club has been most common under the "gold rush" conditions of hunts carried out by inexperienced landsmen on those occasions when seals have come close to shore.

The testing of the blink reflex as a check on unconsciousness is probably often omitted. In 1978, several observers stated that they had not seen sealers checking the blink reflex (Jotham, 1978; Rowsell, 1978; Jordan, 1985). It is easy to imagine that the sealers would neglect this check when they were tired or in a hurry, as they usually are, or even when they felt sure that a seal was dead and that no one was watching them.

Observers have noted, too, that sealers have often clubbed several seals before returning to bleed the first seal (e.g., Walsh, 1978), rather than bleeding the first seal immediately after the kill. It should be noted that most of the reported failures to follow in full the specified humane sealing techniques (especially those failures that occurred in later years, when the requirements have become more stringent) do not necessarily imply that those killings were inhumane or cruel. What they indicate was that those killings *might* have been inhumane, and they pointed to the need for improved killing practices, enforcement of the regulations, and effective training.

The most critical question is whether seals are skinned while still conscious. This issue is more significant than the question of whether the seals are skinned while alive, since an animal may be alive by some standards – for example, its heart may still be beating – but if it is in a state of deep irreversible unconsciousness, it is totally unaware of any further experience. The blows to the skull usually produce "brain death", that is, a zero EEG (Blix and Øritsland, 1970), but the seal heart will continue to beat for up to 56 minutes after brain death occurs (Blix and Øritsland, 1970). Death under these circumstances is very hard to define in a way that is suitable for testing by a sealer or a fisheries officer. Many observers have recommended that the regulations should require that a seal be unconscious (i.e., insensitive to pain) before it is skinned, rather than that it be dead (e.g., Jones, 1968; Schiefer, 1968b; Karstad, 1970). In 1978, for the purposes of the Seal Protection Regulations, the Government of Canada adopted a definition of seal death which is essentially a definition of unconsciousness.

There have been numerous accusations that seals have been skinned while still alive, and they have been given wide publicity. A few such accusations based on events seen by qualified observers such as Simpson (1966) have probably been true, but others were probably based on a misconception

and put forward by people who had seen and misunderstood the reflex muscular movements that may occur after the seal is dead. Many observers have noticed these involuntary reflex movements, particularly of the hind flippers, and have cautioned against misinterpreting them as indications that the seal was alive (e.g., Jones, 1968). Søgnen (1968) reported "normal agonal reflex actions", some of which were seen "in fully exsanguinated animals with totally fractured skulls and destroyed brain tissues." Scott (1977) reported a seal that swam vigorously on the surface for 9–12 metres after being shot in the head: "The post mortem showed that most of the seal's head had been destroyed, suggesting that the swimming could be attributed to reflex action."

The possibility does exist, however, that a seal might be conscious at the time skinning is started, although it does not make any obvious movement. The reason is that many harp seal pups "freeze" when approached. Simpson (1966) reported that when seals reacted in this manner, they remained immobile, and that "practically anything could be done with such an animal without it moving." Karstad (1970) suggested that a seal which regained consciousness after clubbing might immediately go into a freezing reaction and be conscious when skinning began. Johansson (1967), too, acknowledged the possibility that a seal in the freezing (or "opossum") reaction might be conscious when skinning began. He pointed out, however, that "because of the very rapid and massive surgical shock and hemorrhage, it is certain that consciousness would be quickly lost." It is impossible to be sure by direct observation what proportion of seals suffer in this way, but the data on the proportion of skulls properly crushed indicate that the proportion is extremely small under most circumstances. Further, it was in order to obviate this risk that the requirement for the sealer to check the blink reflex was introduced, and if this procedure is followed, it should be impossible for any seal to be bled or skinned while still conscious.

The state of consciousness or unconsciousness at the time of killing is often difficult to determine after the fact. A crushed skull before death has usually been accepted as evidence that the seal was unconscious at the time of death. Even if the skull is not crushed, unconsciousness might result from brain hemorrhages, depending on the degree and location of the hemorrhages. Veterinarians who have done post mortem examinations of uncrushed skulls have usually been able to state that some of the seals were likely to have been unconscious as a result of brain hemorrhages when killed; but after examining some other skulls, they have been unable to state whether or not the seal was unconscious when death occurred (e.g., Simpson, 1967b; Schiefer, 1968b; Karstad, 1970).

The crushed skull has served a practical purpose in terms of enforcement of sealing regulations, as it was a definite indication that fisheries officers could check in the attempt to ensure that seals had been humanely killed. In 1968 (Costello, 1968) and 1978 (Scott, 1978), fisheries officers were observed to have required sealers to club until the seal's skull was crushed, even though the regulations did not make the practice of crushing the skull before skinning mandatory until 1984. In practice, however, the crushed-skull practice was subject to possible abuse. Sealers have been observed to crush skulls with their boots after seals had been killed and pelted (Hughes, 1968; Jordan, 1978; Rowsell, 1979a). Only close examination by a veterinarian could have established that the skulls had been crushed after death.

A substantial majority of the veterinarians, humane society officers and biologists who have visited the seal hunt for the purpose of assessing its humaneness have expressed the opinion that clubbing of the young seals is a sufficiently humane method of killing for the practice to be accepted. They have noted many instances of cruelty and many areas where improvements were needed, and they have made many recommendations for achieving the changes needed to eliminate the cruelty. On the assumption that the various improvements recommended would be implemented, most observers have considered that clubbing could be done humanely, even though some were opposed on principle to this method of killing, and many have found it to be as humane as, or more humane than, slaughterhouse operations. On the other hand, a few observers (Simpson, 1966, 1967a; Jordan, 1978) have judged clubbing to be unacceptably inhumane and incapable of being rendered humane, and have consequently called for its abolition.

The Royal Commission believes, from the evidence put before it, that under the present regulations, given the existing enforcement and educational programs of the Department of Fisheries and Oceans, the very great majority of harp seal pups are killed in a manner which meets a high standard of humane killing. If the requirements for checking the blink reflex and for immediate exsanguination were invariably observed, virtually no animals would be killed in other than an extremely humane way. It is essential, therefore, that if further clubbing of harp seal or hooded seal pups does take place, the Department should maintain, and if possible improve, the level of its enforcement and educational programs.

It appears to the Royal Commission that the principal danger which would threaten the maintenance of a consistently high standard of humaneness in a hunt if it were allowed in future is that of the local development of special conditions in circumstances where adequate supervision is impossible, or when inadequately trained men are engaged in the hunt. That it

was possible for such a circumstance to arise in 1981, after the regulations and supervisory organization had been in place and functioning fairly effectively for some 13 years, emphasizes the reality of the threat and the dangers of complacency. If there is any risk of such a situation developing in the future, the Department should ensure that all sealing in the area is effectively prohibited before the hunt can commence.

Pre-Kill Stress

A major concern relating to humane killing is the stress that the animal undergoes prior to the actual killing (e.g., UFAW, 1967). This is a particular concern in operations where the killing occurs at a centralized point to which the animals must be brought, as it does, for example, in slaughterhouse operations and at the Pribilof fur seal hunt.

Most observers of the Canadian hunt agree that the seal pup experiences little stress before it is killed (e.g., Hughes, 1978b). The killing does not occur at a central location, and the pups need not be moved, or even touched, prior to killing. Seal pups appear to be unaware of what is happening to other nearby seal pups (e.g., Johansson, 1967; Ronald, 1970; Scott, 1971). They show little apprehension of humans if they are approached cautiously, but may attempt to escape if alarmed (Platt, 1970). When escape is not possible, they may threaten to bite, though they rarely actually do so, or they may defecate (Simpson, 1966; Helmboldt, 1968). Other alarmed seals may react by freezing (Simpson, 1966). Although seal pups may be alarmed at the approach of a sealer, the distance within which they show this alarm was estimated to be only three to four metres (CVMA, 1979). Thus the seal pup would feel stress for only a very short period of time, if at all, prior to the kill.

Impact on the Mother Seal

Another important concern in the question of humane killing is the impact of the killing on other animals that may observe the killing or otherwise suffer as a consequence of the kill. Since, when harp seal pups are clubbed, other pups are apparently unaware of what is happening, the only issue of concern is the impact on the females.

Many of the observers of the harp seal hunt have commented on the reaction of the mother seals as the pup was approached and after the pup was killed. Highly variable reactions have been reported, a result, at least

in part, of wide individual variation among the seals, as well as of variation related to the time during the short nursing periods when the kill occurred.

The proportion of female seals reported to have left their young and entered the water when a sealer approached has varied from very low to 95%. There is similar variability in the reports of interest shown by females in the carcasses of their young. Some observers believe that there is a strong pair bond between mother and young while others consider that this bond is weak. Harp seals produce milk only under the stimulus of suckling, and females which lose their young quickly cease to produce milk. The harp seal has a very short nursing period compared to that of other large mammals; the suckling period is only eight to 12 days (Lavigne, 1979; Stewart and Lavigne, 1980).

Even less is known about the mother-pup relationship of hooded seals, although Greendale (1985) concluded from his observations that it was stronger than that of harp seals. For hooded seals, the nursing period is even shorter than it is for harp seals, lasting only four days (Bowen et al., 1985).

Measures suggested to minimize distress to females include not taking pups whose mothers try to defend them and delaying the hunt until most pups have been weaned. In practice, both these measures would encounter some problems. This question is discussed further in Appendix 20.3.

Effects of Sealing Vessels on the Seal Pups

An issue occasionally raised is the effect on the seal pups produced by the ice-breaking activity of the sealing vessels. Simpson (1966, 1967a) reported that she observed several whitecoats crushed between the ship and the ice or between pans of ice; other seals that were knocked into the water attempted to swim to other ice pans, and some were able to haul out onto them. Watson (1985) reported that he had witnessed 43 seals killed by three Canadian Coast Guard vessels and numerous seals "run down" by sealing ships. No other observers have reported seals being crushed by ships. Bourne (1966) stated that "after much questioning and observation in similar areas I have no evidence of whitecoats being crushed between ships and the ice." Pimlott (1967) observed 15 seal pups that appeared to have been in the path of a vessel. All but one were unharmed, and those that were dumped into the water were able to get back on the ice. (The fifteenth was not injured, but was lost from sight behind a cake of ice.) Walsh (1967) ob-

served seven pups that fell into the water; all were able to climb back onto floating ice or to swim to it, aided by the presumed mother.

The weight of evidence appears to the Royal Commission to suggest that few seal pups are killed by sealing or other vessels passing through the ice on which they are lying. This situation should not be compared with that in the Arctic, where passage of large ice-breakers through heavy ice may cause the deaths of some ringed seals. This question is discussed further in Chapter 23.

Other Issues

Adult and pup harp seals both shed tears copiously on the ice. It has been suggested that this tearing occurs in reaction to distress prior to being killed or to grief at the death of a pup. There is, however, no biological evidence to support this suggestion (Appendix 20.4).

Johansson (1967) stated that natural enemies or low-flying aircraft could frighten females into the water "apparently even if they are in active labor" and that "pups born in the water will drown." He did not indicate that he had observed this happening, nor did he provide any supporting evidence or reference for his claim. Both Sergeant (1985) and Lavigne (1985) indicated that they knew of no evidence to support the claim of a seal in labour being frightened into the water and giving birth under water to a pup that consequently drowned.

Other Canadian Clubbing

Clubbing has been used in eastern Canada as a method of culling grey seals. Adults are shot, and pups are shot or clubbed at the whelping areas in mid-winter (Hoek, 1985). While this clubbing has not been observed independently with a view to evaluating its humaneness, Webb (1984a) did observe a demonstration clubbing of six grey seal pups. The skulls were smashed and the seals were unconscious, but after five to eight minutes three pups began shallow breathing that continued for some time before they died.

Northern Fur Seals

Northern fur seals are harvested by means of clubbing on the Pribilof Islands in the United States and on the Commander Islands and Robben Island in the U.S.S.R. (NPFSC, 1983). The 1982 harvest totalled 33,079 fur seals (NPFSC,1983).

Northern fur seals are highly gregarious on land (Lander, 1979), and the method of harvesting them in the Pribilofs takes advantage of their gregariousness. The seals taken are bachelor bulls, generally three or four years old, which have not yet begun to breed (Lander, 1979). These bulls haul out in herds in areas near to, but separate from, the areas used as harems and rookeries (Walsh, 1968). Driving them to the killing areas does not disturb the harems or rookeries (Denney, 1971).

When seals are to be killed, groups of about 100 are driven inland to killing areas, where they are formed into a larger herd and held in check (Simpson, 1968). Small groups are cut out from the larger group, and the seals are clubbed with one or more blows of a hardwood club 155 centimetres long that resembles an elongated baseball bat (Simpson, 1968; U.S., Veterinary Panel, 1971). Seals that do not conform to the size criteria or that have damaged fur are released. Once a small group has been clubbed, the seals are bled by opening the thorax and severing the arteries and/or puncturing the heart (U.S., Veterinary Panel, 1971). They are then skinned.

In the late 1960s and the early 1970s, a number of animal-welfare officers and veterinarians visited the fur seal hunt in the Pribilof Islands in order to assess the humaneness of the hunt and to attempt to devise better methods of harvesting seals. Pfeiffer (1981) observed the hunt in 1980 to see how it might have changed from the early 1970s.

Driving of the Seals

One of the major issues raised by this hunt is the effect on the seals of the drive from the hauling grounds to the killing areas. Although fur seals travel well over land, they are highly susceptible to overheating and exhaustion (Walsh, 1968; Keyes, 1980) and may suffer if they are pushed too hard, or if the temperature is too high. The drives were begun in the early morning in order to have them completed before the ambient temperature became too warm (Denney, 1971). The seals were driven slowly (Simpson, 1968) and were given rest periods "where distance, ambient temperatures or

terrain seemed to dictate" (U.S., Veterinary Panel, 1971). However, the seals were sometimes driven over obstacles such as boulders or driftwood when they could have been driven around them (Walsh, 1968).

Fur seals do suffer during the drives. Some seals have died in warm weather (Walsh, 1968), and one died on a drive during the week when Pfeiffer (1981) was present. Davies (1967) reported that many seals collapsed in apparent exhaustion. Wooldridge (1967) discovered vesicular emphysema in the lungs of some seals, but Simpson (1968) found that similar lesions had occurred at the time of death and not on the drive.

Later observers did not record the same degree of exhaustion. Denney (1971) reported that "in a few instances some individuals would get tired and drop out of the pod, but would usually follow and rejoin the herd after resting." Pfeiffer (1981) reported that a few of the smaller seals became fatigued easily, but that most of the seals arrived in good condition.

Observers reported that the length of drives was reduced from a distance, in 1968, of 150–1,200 metres with an average of 485 metres (U.S., Dept. of Interior 1968), to a distance, in 1980, of 120–1,000 metres with an average of 345 metres (Pfeiffer, 1981). The terrain had prevented removal of obstacles, however, and the seals had to be driven over them.

Killing Procedure

On the killing grounds the herds are allowed to rest for about half an hour. They are then separated into pods, generally composed of about six to 10 seals. During the drive and the separation into pods, some of the females and larger males are released, but others remain in the pods (Walsh, 1968; U.S., Veterinary Panel, 1971; Pfeiffer, 1981). When clubbing of the pod has been completed, the remaining females and larger males are released and driven from the area (U.S., Veterinary Panel, 1971). The presence of these unwanted animals complicates the clubbing: pods may be larger because of the presence of the unwanted animals, blows may be less accurate, and the larger males may be dangerous to the clubbers (Walsh, 1968; U.S., Veterinary Panel, 1971).

The U.S., Dept. of Interior (1968) reported that when a pod is being clubbed, the time from the first to the last blow ranged from five to 48 seconds, and that the killing of each seal required an average of two to three seconds. The U.S. Veterinary Panel (1971) reported that no more than 20

seconds usually elapsed from the start to the end of the stunning, but that the process occasionally took longer. The seals in the killing pods are present in the immediate vicinity of other seals being killed and are aware of this activity. The killing period presumably creates a high degree of stress that lasts until the seal is stunned or is released as unwanted.

The sealers who do the clubbing are experts who have worked their way up through the ranks and are among the highest-paid members of the crew (U.S., Dept. of Interior, 1968; Denney, 1971). They work continuously, under close supervision, killing pod after pod until breaks are called, about every two hours (Simpson, 1968; U.S., Veterinary Panel, 1971). The processes of bleeding and skinning are each done by separate groups of the crew.

The fur seals are stunned (or killed) with a blow to the cranium. Davies (1967) stated that:

> *There is no doubt, but that a blow to the head of a fur seal of the age group killed on St. Paul Island, will, if accurately delivered, shatter the skull of the animal concerned. Unfortunately, under present conditions, with the animals milling around in front of the hunters, accuracy is not always achieved.*

When the first blow was inaccurate, clubbers would give the seal a second or third blow (Simpson, 1968; U.S., Dept. of Interior, 1968). The proportion of seals receiving more than one blow has been recorded variously as 12% (Davies, 1967; Wooldridge, 1967), 13.6% (Simpson, 1968), and 8% (Pfeiffer, 1981).

When a seal was struck accurately, it would immediately collapse (U.S., Veterinary Panel, 1971). Body movements ceased and could not be elicited, but respiration sometimes continued. Of 3,200 seals that the Veterinary Panel observed being stunned, none regained consciousness prior to exsanguination.

Exsanguination followed stunning by 2–3 minutes (Wooldridge, 1967) or by 30–60 seconds (U.S., Veterinary Panel, 1971) and quickly produced death. There was no evidence that any seal suffered during skinning or that any seal had been skinned alive (Davies, 1967; Wooldridge, 1967; Simpson, 1968; U.S., Veterinary Panel, 1971).

With one exception, observers of the killing of fur seals appear to have been generally satisfied with the humaneness and efficiency they observed in the process. In particular, Simpson (1968), Denney (1971), the U.S. Veterinary Panel (1971), and Pfeiffer (1981) stated that the kill was reasonably humane, although they did recommend some improvements. Davies (1967), on the other hand, could not accept that clubbing of fur seals was humane.

Russian Harvest of Northern Fur Seals

There is little information available on the killing methods used on the Russian Islands. In a paper presented to the 23rd Session of the North Pacific Fur Seal Commission (U.S.S.R., 1980), a method is briefly described. The fur seals on the Commander Islands are driven from the hauling ground and are then stunned by a blow to the nose with a bat that is about two metres long and thicker at the striking end. The unconscious seals are next stabbed in the heart for quick exsanguination and then skinned. Bruises are sometimes seen in the blubber, caused by inaccurate blows, and some seals outside the commercial size range are occasionally taken by accident. The method is considered the most rapid and effective harvesting procedure in that it produces instantaneous unconsciousness and death very soon afterward (U.S.S.R., 1980).

Cape Fur Seals

Cape fur seals are harvested by clubbing in South Africa and Namibia. The seals, aged seven to nine months, are harvested by similar methods at a number of colonies along the coasts of the two countries (Shaughnessy, 1976; David, 1985). These seals are driven from the beach and clubbed in a manner similar to that practised on the Pribilof Islands. The harvest in 1975 amounted to approximately 75,000 seals (Shaughnessy, 1976), but the number has been greatly reduced since then (Dixon, 1984).

Two American veterinarians inspected the hunt at two sites in 1974 and 1975 (Shaughnessy, 1976). In 1974, the killing techniques were not of sufficiently high standard and were judged to have been inhumane, but in 1975 the harvest satisfied the veterinarians' criteria of humaneness (Shaughnessy, 1976). The two veterinarians concluded that clubbing and bleeding, if properly practised, was the most efficient way of killing the Cape fur seal pups.

Platt (1983) observed the Cape fur seal harvest in 1977 at a different site from the two sites visited by the American veterinarians. The site he visited had a reputation as the best and most efficient commercial sealing operation in Namibia. He cautioned that the conditions at other sealing operations were not as good as those he had observed. Provided that the standards at the other operations have been upgraded, the harvest of Cape fur seals in South Africa and Namibia appears comparable in humaneness to that of the harvest of fur seals in the Pribilofs. The clubbing and bleeding are performed under controlled conditions, but the seals experience stress during the drive to the killing area and during the actual killing, which occurs in the presence of other seals.

Other Seals

South American fur seals are killed in Uruguay (Vaz-Ferreira, 1979b). The harvest totalled 10,496 in 1979, but only 1,375 in 1982 (FAO, 1984). Groups of 1,000 or more seals are driven inland to concrete corrals, where they may be held for two to five days before clubbing (Vaz-Ferreira, 1985). South American sea lions are also clubbed in Uruguay. The annual harvest amounts to approximately 3,000 pups (Vaz-Ferreira, 1979a, 1985). Vaz-Ferreira (1985) stated that the same methods of killing fur seals and sea lions have been used in Uruguay for many years, and that no better or more humane method is known that could be used on the islands.

In the U.S.S.R., Caspian seals were formerly clubbed on the islands where they gathered (Badamshin, 1960). They are now killed on the ice by hunters either working from vessels or using sleds to encircle the seals with nets. Only pups are harvested, and there is an annual quota of 50,000 on these young animals (Popov, 1982). It is suspected that, as in the past, the seals are killed by clubbing.

In the U.S.S.R. White Sea, harp seals are hunted from helicopters. The animals are killed with clubs. The carcasses are then placed in a net slung from the helicopter and transported to shore for processing (Nesterov, 1973). Up to 15% of the pups may regain consciousness in transport or on shore. From this description it appears that this hunt is less humane than the recent Canadian harp seal hunt. In 1971–1972, the Russians were looking for alternative harvesting methods to eliminate disadvantages in their method (Nesterov, 1973; Ponomarev, 1973). Nevertheless, the method is still in use (Barzdo, 1980).

Harbour seals and grey seals are clubbed in Iceland (Einarsson, 1978).

Clubbing was used to kill harbour seal pups in the United Kingdom in 1967 (Jones et al., 1968). The Universities Federation for Animal Welfare (UFAW, 1968) considered clubbing to be an effective method of producing rapid unconsciousness and death in harbour seal pups, but believed that it was an ineffective method for grey seal pups because in the latter species the shape and thickness of the skull would require a very heavy blow. Clubbing is not specifically prohibited by the U.K. *Conservation of Seals Act, 1970,* but its use has to be specified on a sealing licence. Since 1970, most killing of seals in the United Kingdom appears to have been effected by shooting (UFAW, 1970/1971–1978/1979).

Shooting Seals

Shooting of seals is probably the most common killing method in terms of the number of species that are shot and the number of locations where seals are shot. (See Table 20.1.) Seals are generally shot at a distance, and this chapter is concerned with the humane aspects of such shooting. Shooting at close range as a substitute for clubbing is considered in the section entitled "Experimental Killing Methods".

Bonner (1970) reviewed the shooting of seals from the viewpoint of humane killing. He considered that seals should be shot in the brain, as shots in the neck or heart were not effective in producing rapid death. The seal's skull is rather fragile, and even a relatively low-powered bullet will produce a massive wound on striking the brain case. Bonner considered that under normal conditions of shooting in England (at ranges of up to 35 metres), any bullet with an energy of 474 joules (at 90 metres) was quite adequate for killing British seals, provided that the bullet struck the brain case (although he did consider it prudent to specify more powerful ammunition). Bonner's specifications would permit the use of .22-magnum ammunition, but not low-powered standard .22-calibre ammunition.

This view is not entirely applicable to Canadian conditions. Many Canadian hunts take place, or have taken place, under conditions which make it impossible to obtain an acceptably high proportion of kills with head shots. This limitation applies to all types of operations, including culling, bounty hunting, and commercial and subsistence hunts. The causes include long-range shooting, shooting from moving boats, and shooting at seals in

the water. Under such circumstances, a much higher proportion of instantaneous or quick deaths may be achieved with heavier or high-powered ammunition, which makes a much larger wound and has more shocking power. Canadian regulations specify ammunition requirements only for shooting seals in the Gulf and Front areas. Centre-fire cartridges that are not made with metal-cased hard-point bullets must be used, and they must have a muzzle velocity of not less than 1,800 feet per second (550 metres per second) and a muzzle energy of not less than 1,100 foot pounds (1,490 joules).

However, heavier higher-powered ammunition often sacrifies accuracy for killing power, and is also considerably more expensive. (For example, prices in Pangnirtung, in November 1985, were $0.066 for .22-calibre short, $0.23 for .22-magnum, $0.652 for .222-calibre, and $0.975 for .303 soft-nosed). Furthermore, differences in size and thickness of skull among species of seals mean that ammunition suitable for killing one species may be inadequate for killing another. The Royal Commission believes that serious consideration should be given to prohibiting the shooting of seals with low-powered .22 ammunition and that additional specific restrictions might be required for some hunts, depending on the species of seal hunted and the normal conditions of such hunting, especially the normal range at which the shooting takes place. Because such restrictions could cause hardship to sealers, they should be discussed with the sealing communities that would be affected prior to their enactment.

Shooting is clearly a humane way of killing if the animal is killed outright, but in any large-scale operation some proportion of seals will merely be wounded. These animals may recover or may die some time later; in either event the shooting inflicts a serious degree of suffering. The critical question in assessing the humaneness of shooting operations is what proportion of the animals hit are only wounded. When considering seals that have been recovered, most studies of hunting efficiency have not distinguished between seals that were wounded first and later killed and those that were killed by the first shot. Furthermore, many seals that are shot and killed in the water sink before they can be recovered (e.g., McLaren, 1958), and wounded seals that escape to die (or survive) usually cannot be counted separately from seals that are killed, but sink before they can be recovered. Consequently, the rates of wounding are unknown for most shooting operations.

The use of shotguns in hunting seals is also likely to lead to the painful wounding of a number of animals unless the guns are loaded with a solid projectile (Walsh, 1978). Since 1966, the regulations have prohibited

the use of shotguns unless rifled or "Poly-Kor" slug shells are used, and then only if the shotgun is 20 gauge or more. There seems to be a need to examine the meaning of these regulations and their practical application, to ensure effective prohibition of the use of these weapons in ways which could lead to a significant level of wounding of seals.

Harp and Hooded Seals

Harp seals have been shot by landsmen using longliners or small motorboats in the Gulf, by landsmen and sealers in large Canadian and Norwegian vessels at the Front, and by Inuit in the eastern Canadian Arctic and in Greenland (Reeves, 1977). Hooded seals have been shot in similar conditions at the Front and in Greenland (Kapel, 1975; Rowsell, 1975). Both species may be shot in the water or on the ice. Shooting is probably practised by the Norwegians in their hunt for harp and hooded seals off Jan Mayen, and in their hunt for harp seals in the Barents Sea, though there is little information available on these hunts. Shooting of these seals in the Arctic is considered in the next section.

In contrast to the large number of veterinarians, animal-welfare officers and biologists who have assessed the humaneness of clubbing of seals, only seven observers making 10 visits have observed the shooting of harp and/or hooded seals to assess its humaneness. Early observers of the shooting of harp and hooded seals at the Front and in the Gulf noted a number of instances of wounding of seals or of the killing of seals that could not be recovered (England, 1924; Lillie, 1949, 1955; Davies, 1965).

More recently Søgnen (1968) and Platt (1970) observed the Norwegian shooting at the Front. The shooters were generally expert marksmen, although Platt observed some indifferent shooting. They used expanding bullets. Seals were usually killed by a shot to the head or neck. Søgnen observed a few seals that were not killed by the shot; these surviving seals were usually clubbed with a hakapik. He considered the methods used in the hunt humane "when compared with accepted methods employed in hunting and slaughterhouses" and stated that he could not find a better killing method, given the conditions of the hunt.

Platt (1970) was of the opinion that some conditions for shooting beaters from the ship were not good – it often required three to five shots to kill a seal – and that the marksmen should have waited to fire until the ship slowed down. He also observed the shooting of adult harp seals in moulting

patches on the ice; he examined hundreds of carcasses and found only one seal that had been left wounded. "By far the majority of seals I saw killed", he stated, "died in a manner comparable to that of food animals slaughtered on land."

Rowsell (1975) observed the shooting of hooded seals and beater harp seals from a large Canadian sealing vessel at the Front. Both the male and the female (mother) hooded seal were shot, and the pup was then clubbed. The seals were next winched aboard to be bled and skinned. Because some seals were conscious when winched aboard, Rowsell recommended that all hooded seals be struck with the hakapik before being taken on board. This recommendation was made a government requirement in 1977.

In 1981, Rowsell and Walsh observed the shooting of hooded seals from large vessels at the Front (Rowsell, 1981; Walsh, 1981). Rowsell noted that males were shot and pups were clubbed, but that females were left alone, except for one that was mistaken for a male and shot. After males were shot, they were struck with a hakapik. Walsh recorded that some seals were bled before they were winched aboard, but that most were winched before being bled. Rowsell remarked that a sealer checked the corneal reflex of seals brought aboard. The marksmanship was excellent on two vessels, and any seal that showed any movement was shot a second time. On a third vessel, however, the marksmanship and general attitude of the sealers were of considerably lower quality (Walsh, 1981).

Four observers who were present at the Front in 1977 assessed the shooting of harp seals by landsmen operating from longliners or from small motorboats (Hughes, 1977; Rowsell, 1977; Scott, 1977). Marksmanship was good on the longliner from which Rowsell and Scott were observing. Rowsell examined 76 carcasses of seals – one of them a hooded seal – that had been shot in the longliner operation; 10 of the seals (13%) would not have been rendered unconscious instantly. Rowsell compared this observation with his 1975 observations that unconsciousness would not have been instantaneous in 8% of hooded seals that were shot, but cautioned that shooting conditions were more difficult in the longliner operation.

Hughes (1977) observed 31 carcasses of seals that had been shot from another longliner; he considered that these seals had been killed cleanly. Of 41 seals shot from small motorboats which he examined, 39 had been killed with shotguns loaded with either slugs or shot, and two had been shot with rifles. The use of shotguns may only wound seals or may seriously damage the pelt (Walsh, 1978).

Arctic Seals

The principal species hunted throughout the Arctic is the ringed seal; smaller numbers of bearded seals are also hunted. In the eastern Canadian Arctic, some harp seals and a very few hooded and harbour seals are also taken. The great majority of these seals are killed by shooting. When seals are shot in the water in the Arctic, their loss through sinking is high. This loss varies not only among the species of seals, but also seasonally.

In general, the loss rate diminishes during the summer, for the animals become more buoyant as the thickness of their blubber increases. For harp seals, Haller et al. (1967) reported a decline in the loss rate from 65% at break-up to 50% in July, 37% in August and 0% in October. For ringed seals, the loss rate dropped from 28%–52% in June–July to 4%–16% in August–September (Davis et al., 1980). Bearded seals are less buoyant than ringed seals and may sink at any time of the year (McLaren, 1958); Burns (1967) reported a loss of at least 50% of bearded seals killed in Alaska.

Although the proportion of animals not retrieved after shooting is high in the Arctic, it cannot be taken as a measure of the proportion of animals wounded but not killed outright. No useful data seem to be available on this point.

A number of observers (Haller et al., 1967; McLaren, 1958; Smith and Taylor, 1977; Davis et al., 1980) have described hunting techniques in which the seal in the water is deliberately wounded by a shot so that the hunter can approach it and be in a position to retrieve the carcass after killing the animal with another shot. This practice must cause a degree of suffering. The Royal Commission has no data on the number of animals treated in this way and no information on the length of time which elapses between the deliberate wounding of an animal and the final kill. Its members believe, however, that in general it is probably short compared to the period of suffering which would be experienced by an animal which is accidentally wounded and not recovered.

Seals are also shot in winter and in spring before break-up, at breathing holes and when hauled out on the ice. Seals killed at breathing holes are shot at very close range, but even so, some seals may be wounded and escape (Haller et al., 1967). In the Thule area of Greenland, a harpoon is sent down the hole immediately after the shot is fired, to retrieve the seal (K'ujaukitsoq. 1985). Shooting on the ice is reported to be generally accu-

rate, and few seals are missed, although with the increasing use of snowmobiles it appears that more shots are now fired per seal killed (Wenzel, 1981). This observation may imply less careful shooting and an increased rate of wounding.

Further information on the arctic seal hunt is given in Appendix 20.5.

Grey Seals

Grey seals have been killed in Canada, chiefly in efforts to control their numbers in order to benefit fisheries. Both culling by government employees and bounty schemes have been used. Culls were carried out from 1967 to 1984, at sites on the Gulf of St. Lawrence and on the Atlantic coast of Nova Scotia (Canada, DFO, 1985). The annual kill ranged from 152 (1968) to 2,385 (1983) and included an average of 81% pups. Adults were shot on land, on the ice, or in the water; pups were shot or clubbed on land. To obviate the risk of death by starvation if the mother is shot, the attempt has been made to kill all pups at a site.

Webb (1984a, 1984b) observed the cull in 1982 and 1984. He was concerned that more effective ammunition be used, although Bonner (1970) found that similar ammunition (30.06 soft-nosed) was considered satisfactory for humane killing in the United Kingdom.

Bounties have been applied to grey seals since 1976; the number paid has ranged from 496 to 952 (Canada, DFO, 1985, Appendix LX). Most seals on which bounties are claimed have probably been shot, but some have been taken incidentally in nets. Sinking rates for shot seals are high, ranging from 50% to 76% (Mansfield and Beck, 1977), but no estimate of the proportion wounded is available. Licence to kill for a bounty is limited to bona fide fishermen, but the Department of Fisheries and Oceans (DFO) considers that the loss and wounded rates for seals are higher than in the culling operations because participants in the latter process use high-powered rifles and are under direction. Bounty hunting is prohibited in the whelping season, apparently to prevent pups being orphaned, but at least one breach of this regulation has been recorded (Dudka, 1978).

Grey seals have been hunted extensively in the United Kingdom, mainly for the benefit of fisheries. The adults have generally been shot on land or in the water with high-powered ammunition, and the pups have been

shot at close range with lighter weapons. Most reports record the operations as satisfactorily humane (e.g., UFAW, 1967/1968), though some problems with orphaned pups have been noted.

There have been conflicting reports of the effect on the surviving seals of shooting in a colony. Scott (1972) describes the animals as stampeding and says that the effect on them "could not be described as humane". Brown (1972), on the other hand, was surprised at the small amount of disturbance that the shooting caused.

Harbour Seals

Bounties were paid on harbour seals until 1964 on Canada's west coast and until 1976 in the Atlantic provinces (Canada, DFO, 1985). Of the sub-adult and adult harbour seals that were reported shot in a survey taken in the Maritime provinces, 65% were retrieved (Boulva, 1973). Almost all the pups were retrieved either because they were taken on land or because they floated when shot (Boulva, 1973). In British Columbia, harbour seals were generally shot in the water by hunters on land, and because they represented a very small target, the result was usually either a kill or a clean miss (Bigg, 1985a).

In the United Kingdom, harbour seals were harvested commercially in the Wash until 1974. Hunters in high-speed boats approached hauled-out seals and shot or clubbed whatever pups they could on land (Jones et al., 1968). They then shot pups that had escaped into the water. As the pups grew larger, most were shot in the water. Most pups shot in the water by experienced marksmen within a range of 25 metres were killed outright. At greater ranges, or when the shooter fired from a boat, some pups were only wounded and had to be clubbed when they were recovered. Some sealers were highly competent marksmen, but others made many misses. In 1972, four of 10 harbour seals that were shot in the water at close quarters were only wounded (UFAW, 1971/1972).

Sea Lions

Steller sea lions were subject to control programs in British Columbia during the period 1912–1968, in an attempt to reduce their interference with commercial fisheries (Bigg, 1984; Canada, DFO, 1985). The

control programs operated through bounties and organized kills by both fisheries officers and commercial users of the carcasses. In the last period of hunting, between 1958 and 1968, about 19,000 animals were killed in departmental and commercial operations combined (Bigg, 1985b). In the operations carried out by fisheries officers, both pups and adults were killed at the rookeries. Pups were killed ashore, but adults were killed both in the water and where they were hauled out. The majority of adults were shot from boats while the sea lions were on the shore (Bigg, 1984, 1985a).

Sea lions are difficult to kill; high-powered rifles are needed for this purpose, and even when they have been used, many animals have merely been wounded. Bigg (1985a) believed that the most humane method of culling sea lions was to shoot the pups on land. During the Second World War, quite large numbers of sea lions were killed by the Canadian navy and air force, but little information is available about the numbers involved. Steller sea lions were protected on the B.C. coast in 1970 (Canada, DFO, 1985).

Humaneness of Shooting

A bullet that strikes the brain case of a seal with sufficient energy will produce an instantaneous and humane death (Bonner, 1970), but any shooting at a distance or under difficult conditions will produce a certain proportion of inaccurate shots. In such circumstances, a much higher level of humane kills will be obtained with high-powered ammunition than with low-powered .22 loads.

Shooting is most accurate when the seal is on land or on ice and the shooter is on solid footing: land, ice, or a large ship that is proceeding slowly in calm waters. Under these circumstances, accuracy is high, and few seals are wounded or lost (Haller et al., 1967; Søgnen, 1968; Davis et al., 1980). The replacement of harpoons by rifles in the Arctic has considerably improved the humaneness of hunting seals when the seals are on the ice. Shooting is less accurate when the seal is in the water, even if the shooter is on solid footing. In these circumstances, the seal presents a much smaller target, and there are likely to be many more misses than wounding shots unless the shooter has deliberately tried to wound the seal to prevent its sinking.

There is less certainty in shooting seals on land or on the ice, but especially in the water, from an unstable platform such as a small motorboat

or a large vessel in rough seas. Greater numbers of seals are probably wounded under such circumstances. Hunting methods that deliberately wound or harass a seal so that it can be killed at close range are sometimes used to avoid sinking losses (McLaren, 1958; Haller et al., 1967; Wenzel, 1981), and these cannot be considered satisfactorily humane. Nevertheless, some of the non-shooting killing methods that have been proposed in the Arctic to avoid sinking losses, such as the use of harpoons and nets (McLaren, 1958; Burns, 1967), are probably more inhumane than is shooting in open water.

Netting Seals

Harp seals are taken in nets along the Labrador coast, the lower north shore of the Gulf of St. Lawrence, and the northeastern coast of Newfoundland (Sergeant, 1965, undated; Boles et al., 1983). The seals are taken primarily during December and January on their southward migration, but small numbers may also be taken on their northward migration once the ice has gone in spring. Although the numbers taken have varied considerably from year to year, they have sometimes reached 6,000 harp seals on the lower north shore (Sergeant, undated). Nets may be set out in many configurations to catch harp seals (Beck, 1965; Baril and Breton, undated). More details are given in Appendix 20.6.

Nets are occasionally used in the Canadian Arctic, both in summer and in winter, to take ringed seals (Haller et al., 1967; Davis et al., 1980). They have also been used to take harp seals on the south shore of Hudson Strait, including Port Burwell (McLaren, 1958; Sergeant, 1965).

Netting is also practised in Greenland (Christiansen, 1968; Kapel, 1975), Iceland (Einarsson, 1978), the U.S.S.R. (Sdobnikov, 1933; Mineev, 1971; IFTF, 1977) and Japan (Naito, 1971).

Humaneness

Ronald (1982) conducted a study that involved using divers to investigate how harp seals became trapped in the nets, and how they died. In simple net systems such as those across passages, seals were caught by swimming directly into the mesh or by entrapment in the "hook" where two nets converged. In complex net designs, they were caught in the specially designed trap areas. They generally became more or less entangled in the meshes (Appendix 20.6).

The form in which the death of seals in nets occurs is generally the result of the elaborate set of physiological adaptations which enable seals to stay under water for lengthy periods (Ronald, 1982). Among these adaptations are the following:

- The seal can voluntarily reduce its heart rate for diving and can reduce it even more under stress.
- The seal has a peripheral shunt that, when it is diving, supplies blood, and thus oxygen, only to the heart and brain.
- The seal's muscles are rich in myoglobin, which stores oxygen, and seals can function for some time after the peripheral shunt comes into effect.
- The seal can convert carbon dioxide to a non-toxic form, store the converted form and then release it when it surfaces.
- When the oxygen in the seal's blood and tissues is exhausted, the tissues, including the brain tissues, can undergo an anaerobic period of activity.

These adaptations all play important parts in determining the behaviour of the seal in the net and the way it dies.

Seals that become trapped in nets probably do not realize their danger at first (Ronald, 1982). In laboratory tests, seals tried to push through nets, but did not at first show stress. At some point the seal would struggle violently, probably becoming badly entangled in the net, but possibly escaping. At this point it slowed its heart rate to the minimum and would be fully adapted physiologically for a long dive.

The phase of violent struggle might be followed by a period in which the seal was immobilized as a result of oxygen exhaustion in the myoglobin of the muscles. This inactive phase might be psychologically stressful, as the brain would function to the end, first because of the peripheral shunt and secondly by passing into an anaerobic phase. Because the carbon dioxide in the seal's system would be detoxified and stored, it would not build up and could not cause quick narcosis and unconsciousness.

The seal would thus be conscious until the final onset of death. It would remain in the dive reflex with reduced heart rate and would not attempt to breathe. The lungs of the seals that died in the nets did not contain water

(Ronald, 1982). Instead the animals were considered to have "dry drowned"; this condition, in which a diving mammal will not attempt to breathe underwater, even though it is dying from lack of oxygen, is also seen in beaver.

Most of the female harp seals taken in the early winter net fishery were pregnant. On the basis of studies of other species, Ronald (1982) suggested that the seal fetus might be more resistant to oxygen deprivation than the mother seal, and might therefore survive longer under similar conditions of stress.

Because of the long time it took seals to die underwater, and because the seals were conscious throughout this period, Ronald (1982) concluded that "there is little evidence that the seals are being killed [in the net fishery] in any way as humanely as the club, hakapik or gun methods." This conclusion seems to the Royal Commission to represent an understatement of the degree of inhumaneness involved in killing seals with nets as compared either to clubbing or shooting.

Other Killing Methods

Traditional Arctic Methods

Harpoons were formerly the primary Inuit device for taking seals, but they have now been replaced in many areas by rifles, although they may serve as auxiliary weapons during rifle hunting (e.g., Christiansen, 1968). Harpoons are still used in upper Lake Melville for hunting seals at breathing holes (Boles et al., 1983), as well as in the Thule area of Greenland (K'ujaukitsoq, 1985). Fairly recently, seals were still occasionally harpooned at a breathing hole in the Igloolik area of the Canadian Arctic (Bradley, 1970), and harpoons tied to floats were used occasionally from kayaks in Greenland (Kapel, 1975; Haller, 1978). Smith and Taylor (1977) reported that deliberate wounding of bearded seals to prevent loss by sinking still caused higher losses than the use of harpoons.

Another traditional method of capturing seals that is still used occasionally is to trap the seals at breathing holes, using either seal hooks or harpoon guns (McLaren, 1958; Davis et al., 1980). McLaren reported that seal hooks, which trap the seal in its breathing hole, were used with great

success in the central Arctic. Harpoon guns were more expensive, but probably did not frighten the other seals as much as some other weapons.

These traditional methods all depend on catching and holding the seal until the hunter can kill it. For this reason, they probably inflict considerable pain before the seals are finally killed.

Hooks and Lines

Seals were formerly taken on hooks and lines in the Magdalen Islands (Sergeant, 1965), but this practice was banned in 1964, under the Seal Protection Regulations.

Military Action

When efforts were being made to control the numbers of Steller sea lions on the B.C. coast, the Department of Fisheries arranged for military aircraft and vessels to bomb and strafe haul-out sites in remote areas (Bigg, 1984). This action was taken during the Second World War and in 1958. Such indiscriminate action, which must lead to extensive wounding, and which does not provide reliable information about the numbers of seals destroyed, is obviously highly undesirable.

Poisoning

The only poisoning of seals in Canada of which the Royal Commission is aware was an experiment made in 1950 to test strychnine as a means of protecting salmon nets from grey seal predation (Fisher, 1985). Although the experiment was successful in killing seals, the method was not used further because it involved potentially serious problems created by releasing strychnine into the marine system.

Some Scottish salmon fishermen used poison to destroy seals that were raiding their nets (Bonner, 1970). The strychnine, which causes great suffering prior to death, was placed inside a salmon that was then tied into the net. The method was effective but inhumane; it was banned in 1970. It is understood that cyanide was also tried, but its use was probably discontinued when the use of gill nets to take salmon was banned in 1975 (UFAW, 1974/1975).

Drugs

Harp seal pups are taken to the shore from the ice in the White Sea area of the U.S.S.R.; they are held in enclosures until they have moulted and are then killed. Some of the initial experimental work was described by Ponomarev (1973) and Nesterov (1973), but there are some discrepancies in the accounts. It appears likely that the pups were immobilized with muscle-relaxant drugs such as ditilin (succinylcholine). It also seems probable that the animals were killed with drugs, again probably with ditilin (Nesterov, 1973). At one time a quota of 24,000 fur seals was taken in this way (Barzdo, 1980).

The method may have some advantages from the point of view of centralization and quality control, but it is open to serious criticism for its inhumaneness in at least two aspects. First, the collection of the animals and the subsequent packing into containers for the helicopter journey to the shore would be traumatic, although the trauma would be mitigated for the second stage if the seals were effectively anaesthetized.

Secondly, the drug ditilin is not an anaesthetic, but a muscle relaxant which only immobilizes the animals. The paralysed animals die from suffocation. In humans its use is reported to cause intense anxiety, and its use in euthanasia is not recommended (AVMA, 1978). Its use, as in the U.S.S.R., for transport and subsequent killing, seems highly undesirable.

Experimental Killing Methods

A number of attempts have been made to develop acceptable methods of killing seals, principally as an alternative to clubbing. The chief aim has been to find methods which would be satisfactorily humane on virtually every occasion. There has also been some concern to find a method which would overcome the "brutal" visual image of clubbing.

Most of the effort to find better methods has been focused, in Canada, on the clubbing of harp seal pups, and in the United States, on the clubbing of northern fur seals.

The Royal Commission was not informed of any work aimed at improving the humaneness of operations in which seals are shot.

Shooting

Harp Seal Pups

A long series of experiments by Hughes (1980, 1982, 1983, 1985a) which tested the effects of different types of pistols seems to represent the only case in which a practicable alternative to the established killing methods may have been developed. Any such method must not only be satisfactorily humane, but also capable of effective use under the particular physical conditions of the hunt. Hughes (1980, 1982) laid down the following criteria for the pistol he proposed, and these criteria seem to be realistic:

- The weapon must kill the seal pup instantly without physical or mental pain or distress.
- The weapon must be safe for the sealers to use. For this reason, weapons that fired bullets were not acceptable, and the shotgun ammunition chosen was of a calibre and power to be lethal only over a short distance.
- The weapon must be light and easy to carry, and must not interfere with the sealer's activities. For this reason a pistol was developed.
- The pistol must be easy to load and operate, and capable of being easily serviced and repaired.
- The pistol must be rugged enough to withstand conditions on the ice.
- The pistol should be relatively inexpensive.
- The pistol should cause minimal damage to the pelts.

After a number of experiments, the Canadian Veterinary Medical Association Humane Practices Committee stated that "the .38 calibre single shot pistol is capable of producing humane death, i.e. immediate and terminal unconsciousness in Grey Seal pups" (CVMA, 1984). Hughes (1985a) has stated that he is now satisfied that further trials are unnecessary, and that "the Accles & Shelvoke .38 shot pistol will undoubtedly kill any seal pup of any age humanely at short range." Accordingly, he believes "that use of clubs and other instruments of manual killing should be abolished and that, in future, the use of an approved gun and ammunition should be made mandatory." He has suggested (Hughes, 1985a) that these pistols be issued

to master sealers by the Department of Fisheries and Oceans at the start of the sealing season and collected at its end. He has further suggested that the barrel could be modified to ensure that the pistol fire shot only and not bullets.

Although Hughes' report (1985a) of his latest tests appears promising, the device he recommends does not seem to have been widely tested by regular sealers under the actual conditions of the hunt. Several additional improvements have been suggested (CVMA, 1984; Webb, 1984a). The Royal Commission cannot, therefore, concur at this stage with the suggestion that the proposed pistol be immediately substituted for the club if the harp seal hunt continues. The Royal Commission does consider that if this hunt continues, the government should support further experiments to ascertain whether this pistol, modified if necessary, can actually be used on a large scale to kill seals humanely and with safety to other people in the vicinity. If the results of these experiments are positive, serious consideration should be given to regulatory action to introduce the pistol in place of the club. In this case the authorities should examine Hughes' proposals (1985a) that the actual killing be restricted to trained master sealers using weapons supplied by the government, and that skinning and other support activities be done by assistants. Experiments should also be undertaken to test the suitability of this pistol for killing seal pups of other species, whose destruction may be proposed as a population-control measure.

Northern Fur Seals

Shooting was tested as an alternative to clubbing of northern fur seals in the Pribilof Islands (U.S., Dept. of Interior, 1968). Standard .22-calibre rifles firing pulverizing cartridges were used to shoot two seals in the head. Although the animals were judged to have been rendered unconscious immediately, heavy gasping continued for several minutes. The bullets passed completely through the skulls and thus could have wounded personnel or other seals.

The U.S.S.R. also tested the shooting of northern fur seals with small-bore guns and pistols (Popov, 1968; U.S.S.R., 1980). The method was not adopted because of the likelihood of wounding non-target animals or of damaging the fur of other target animals (U.S.S.R., 1980).

Other Methods

A wide variety of experiments has been conducted, particularly on northern fur seals, to try to find more acceptable methods of killing. None of those methods of which the Royal Commission has found records showed any promise of success, and nearly all were discarded after limited preliminary experiments. They included:

- mechanical stunning devices, including captive-bolt pistols and others driven by compressed air;
- electric shock;
- gases (carbon dioxide and nitrogen); and
- drugs, particularly succinylcholine, to immobilize prior to mechanical stunning.

The characteristic of the harp seal hunt that makes most of these experimental methods unsuitable is the fact that the seal pups are scattered over a wide expanse of sea ice at low temperatures, rather than concentrated at one killing site. The sealer must travel to the seals, carrying with him the killing device. For this reason the device must be light, uncomplicated and easy to operate. Most of the experimental methods have required either devices that are not readily portable or, at best, heavy and awkward equipment, a means of restraining the seals, equipment dangerous to use on the ice (e.g., electrical devices), or complicated devices (e.g., drug-injection equipment). These methods have been generally tested on northern fur seals and found unsuitable for use on these animals (Keyes, 1980; U.S.S.R., 1980). All would be even less suitable for the harp seal hunt.

Comparative Humaneness of Methods of Killing Seals

The methods of killing seals described above can be evaluated in terms of the following criteria:

- the pre-kill stress suffered by a seal;
- the humaneness of the kill when it is done properly;

- the frequency with which the killing is not done properly;
- the consequences to the seal when the killing is not done properly; and
- the stress to any other seals caused by observing the killing of a seal.

Pre-Kill Stress

Pre-kill stress is primarily an issue in the clubbing of fur seals and the taking of harp seals ashore to keep them in enclosures. On the ice the harp seal pup does not appear to be distressed by the killing activities going on around it (Ronald, 1970), and would undergo stress only very briefly when the sealer moved to club it or shoot it at close range.

Fur seals experience stress during the drive to the killing grounds and the period during which they are held there prior to killing. Harp seal pups would suffer from several forms of stress in the Russian shore-based method of kill.

Pre-kill stress is not an issue in shooting at a distance, but it may be an issue when animals in a group are shot at close range as in some culling operations.

Killing Method When Properly Practised

When performed properly, a single blow of a club or hakapik will crush the skull of a harp or fur seal and render it instantly unconscious (e.g., Davies, 1967; Rowsell, 1973). Prompt exsanguination will ensure that a clubbed seal does not regain consciousness prior to death. When a seal is shot in the brain case at long range with a sufficiently powerful bullet or at short range with a shot pistol, it will instantly be rendered unconscious or killed outright (Bonner, 1970; CVMA, 1984). All of these methods of killing are humane when properly carried out.

Two methods of killing, netting and succinylcholine injection, cannot be considered humane. When seals are netted, they remain conscious until death occurs (Ronald, 1982). Because of the adaptation of a seal to diving, the seal will struggle violently against the net for some time and may undergo considerable stress. Succinylcholine produces paralysis and death by respiratory collapse, but the seal remains conscious until death occurs (AVMA, 1978).

Frequency of Improper Killing

The frequency of improper killing is not at issue with the methods of netting and drug injection. The issue does arise, however, when clubbing is the method of kill.

When seals are clubbed, some are not struck properly with the first blow. These seals may be given additional blows, but even so their skulls may not be fractured. The percentage of seal carcasses with unfractured skulls is often taken as a measure of the degree of improper clubbing because it can readily be checked; but the percentage of seals that are not rendered unconscious will be smaller, as some animals may be unconscious as a result of brain hemorrhages, even though their skulls are not fractured (e.g., Taylor, 1979). Simpson (1967b) recorded that 36% of the 154 harp seal skulls she examined were unfractured, but more recent observers working with large sample sizes have recorded lower percentages with unfractured skulls: 1%–2% for ship-borne sealers and 5%–6% for airborne sealers in a sample of approximately 400 (Jones, 1968); 0.20% of 509 (Ronald, 1969); 0% of more than 400 (Ronald, 1977). Many of the problems relating to improper clubbing of harp seals have arisen when inexperienced landsmen have participated in the harp seal hunt. If the proposed sealing pistol (Hughes, 1985a) is found to be satisfactory, its employment in place of the club and restriction of its use to a select group of professional sealers might reduce the number of harp seal pups that are killed improperly.

The numbers of seals that are shot and wounded are usually not separable from the numbers that are killed more or less instantaneously, but are not recovered. Recorded percentages of seals not recovered have ranged from 0% to 76%, depending on the species of seal, the time of year, whether the seal is on the ice or in the water, and whether the shooter is in a boat or on solid footing. In a sample of 75 harp seals and one hooded seal that were shot and recovered from a longliner, 13% would not have become unconscious instantaneously (Rowsell, 1977).

Consequences of Improper Killing

When a harp seal pup or a fur seal is clubbed improperly, it can be clubbed again very quickly. It is thus usually rendered unconscious with one or more blows, and its skull is probably fractured. If a seal were not rendered unconscious, it would rapidly lose consciousness when exsanguinated (Karstad, 1970), and for this reason exsanguination has been clearly identi-

fied as a step in the killing method to be performed immediately after clubbing and to be completed before skinning is begun.

The consequences of shooting and wounding a seal at a distance will depend on the severity of the wound and the time elapsing before the animal dies, is killed or ultimately recovers. When shooting occurs on land or on the ice, the opportunity will usually exist to kill any wounded animals. Such killing will be carried out whenever possible, when the purpose is to recover the carcass for subsistence, for commercial use or for a bounty. In the large-vessel hunt for harp seals, the preferred procedure is to kill any wounded animals with a club or hakapik as soon as possible, but this procedure has not always been followed. In open-water hunts, it may be possible to kill the wounded animal later, but when shooting occurs in heavy or broken ice, it is probably much less common to kill (and recover) a wounded seal.

Stress to Other Seals

The mother harp seal may suffer distress from being present when her pup is killed or on returning after it has been killed. The extent and importance of such distress is not known. The mother does not suffer distress, however, if the pup is killed after it has been weaned.

Northern fur seals suffer stress if they are present in a small group of which some members are being clubbed. Some northern fur seals which have experienced stress are released after the others in the group have been clubbed (Pfeiffer, 1981).

Stress to other seals does not appear to occur either in the shooting of seals at a distance or in the netting of seals. Shooting a seal may cause nearby seals to dive into the water, but this act may be no more than a normal escape reaction.

Slaughterhouses

Because there appear to be no absolutes in terms of the humaneness of killing animals, the Royal Commission believes that it is appropriate to compare the information about seals with the information available on two other activities in which large numbers of animals are killed in Canada: slaughtering domestic animals in abattoirs and hunting. Consideration is given here only to the larger mammals killed in abattoirs, that is, to cattle,

pigs and sheep, and in big game hunting. In addition, very large numbers of domestic chickens are killed, and large numbers of rabbits and other small mammals, game birds and waterfowl are shot. The number of larger animals killed for human food in Canadian slaughterhouses each year – 3,718,319 cows and calves, 288,243 sheep and lambs, and 13,254,165 hogs in 1984 (Willsher, 1985) – is many times greater than the number of seals killed annually.

Canadian Humane Slaughter Laws

The *Humane Slaughter of Food Animals Act,* which was passed in 1959, applies to food animals that are to be exported from Canada, or that are to be shipped from one province to another. This legislation does not apply to many small slaughtering operations that market their meat within their own province. These operations are subject to provincial jurisdiction, but some provinces have enacted no provincial humane slaughter regulations.

Under the Humane Slaughter Regulations, food animals must, with one exception, be rendered unconscious immediately before slaughter or immediately before they are hung to be slaughtered forthwith. The methods prescribed for rendering the animal unconscious are:

- a blow to the head by means of an approved mechanical penetrating or non-penetrating device;
- a blow to the head applied by manual means for lambs and young calves;
- exposure to carbon dioxide in such a manner as to produce rapid unconsciousness by an approved procedure; and
- application of an electric current to the head of the animal by means of an approved device in such a way as to produce immediate unconsciousness.

The Regulations do not specify the method of slaughter to be used once the animal is unconscious. They do state, however, that in preparing an animal for slaughter and in slaughtering it, the animal is not to be subjected to any unnecessary pain.

The exception to the requirement of unconsciousness prior to slaughter is the method of kill prescribed under Jewish dietary laws. According to this method, the food animal cannot be hung, but must be restrained in an approved device and then slaughtered by means of a rapid cut that simultaneously and completely severs the jugular veins and carotid arteries, causing immediate unconsciousness. Slaughter under Islamic religious laws is performed somewhat similarly.

The requirements for the killing methods set out in the Humane Slaughter Regulations are considerably less specific than are the requirements for clubbing laid down in the Seal Protection Regulations.

Mechanical Stunning

Mechanical stunning may be carried out by means of a penetrating captive-bolt stunner, a non-penetrating captive-bolt stunner, or a gun shot (Grandin, 1980a). The captive-bolt devices may be fired by means of an explosive cartridge or by means of air pressure. They must be held firmly against the skulls of the animals in order to jolt the brain sufficiently to produce immediate unconsciousness (Grandin, 1980a). Regular pistols or rifles may be used to produce unconsciousness by shooting into the brain from a few inches away.

Penetrating captive bolts were considered by Lambooy et al. (1983) and Grandin (1980a) to be sufficiently powerful to stun effectively all slaughter animals, provided that the correct charge and bolt length for the particular animal were used. Non-penetrating concussion stunners have been found effective for cattle, but they are not recommended for calves or sheep.

The major problem in captive-bolt stunning occurs when animals move their heads and deflect the impact of the captive bolt (Grandin, 1980a). Restraining the animal's head in a yoke is practicable only in some plants. Because even the most skilled operators will sometimes miss the mark and fail to stun an animal properly, observers have recommended that a second captive-bolt device should be loaded and kept ready for an immediate second shot (Grandin, 1980a).

Von Mickwitz and Leach (1977) examined the operations of a number of slaughterhouses in the European Community (EC). Captive-bolt stunning of calves in four slaughter plants was judged to have been unsatis-

factory, rating 5.0 on a scale where 1 was rated as very good and 6 was rated as poor. Stunning of cattle by penetrating captive bolt (in 19 plants) was considered to have been adequate, rating 3.9 on the scale just mentioned, but concussion stunning (in three plants) was held to be considerably better, rating 2.4. Corneal reflexes were still present in some animals after captive-bolt stunning. Stunning of sheep with the penetrating captive bolt (in six plants) was considered to have been satisfactory, rating 3.0, but concussion stunning (in one plant) was poor, rating 6.

Essentially, these operations provided no objective methods of testing that determined when an animal was improperly stunned. Instead, a slaughterman would rely on his professional experience to determine when an animal should be stunned a second time.

Rowsell (1979b) reported on mechanical stunning of beef animals at three Canadian slaughterhouses. He found that the operations met the requirements for humane slaughter, although he expressed some concern about them. Grandin (1982) visited 14 Canadian abattoirs where cattle were stunned with penetrating captive bolts. She considered eight unsatisfactory because their stunning pens held more than one animal at the time of stunning.

Manual Stunning

Under the *Humane Slaughter of Food Animals Act*, lambs and young calves may be rendered unconscious by a blow to the head applied by manual means. Many other small animals are killed by manual clubbing in small Canadian slaughterhouses (Hughes, 1985a). Rowsell (1979b) reported on the clubbing of lambs with a steel bar at a Canadian packing plant. Several lambs were confined together in a small pen, and there was little room to swing the club. The lambs moved and shifted their heads; consequently, one was hit on the neck, and another required two blows to stun it. Blink reflexes were still present in some of the lambs that had been struck.

Electrical Stunning

Electrical stunning is used especially for pigs, but also for sheep (Von Mickwitz and Leach, 1977; Grandin, 1980a). Instantaneous unconsciousness is obtained in this method by passing an electric current through the brain of the animal. The animal must then be bled before it recovers conscious-

ness. Unconsciousness lasts at least 30 seconds in pigs (Hoenderken, 1978), but may be as short as 12–15 seconds in sheep (Leach, 1978). The application of incorrect voltages may produce paralysis without unconsciousness. If this occured, the animal would have to experience the electric shock for its duration and then the pain of being hung and bled (Hoenderken, 1978).

An alternative means of applying the current is to send it through the head and body. Current applied in this way will not only cause unconsciousness, but will also stop the heart function and thereby lead to the death of the animal (Von Mickwitz and Leach, 1977).

Von Mickwitz and Leach (1977) found that electrical stunning of pigs was, on average, satisfactory/adequate, rating 3.4 on the scale mentioned earlier, in 17 slaughter plants in the EC. Electrical stunning of sheep (in three plants) was given a less satisfactory rating of 4.6.

Rowsell (1979b) reported on the electrical stunning of pigs at a Canadian slaughterhouse. Unconsciousness was difficult to ascertain, as the blink reflex was obscured by muscular contractions. Although the time from stunning to bleeding was reported generally to have been about 15 seconds, it was over two minutes in some instances, and some of these pigs had regained consciousness before being bled.

Grandin (1982) visited 11 Canadian slaughterhouses where packer hogs were being slaughtered after the use of either electrical or carbon dioxide stunning. All of the plants using an electrical stunning apparatus did a good job of stunning, but three plants took too long (more than 30 seconds) between the times of stunning and bleeding.

Carbon Dioxide Stunning

Carbon dioxide stunning is used primarily on pigs (Von Mickwitz and Leach, 1977; Grandin, 1980a). Inhalation of carbon dioxide at a concentration greater than 7.5% has a rapid anaesthetic effect (AVMA, 1978), but it does not produce instantaneous unconsciousness. Pigs may remain fairly quiet for the first 10 to 15 seconds, but they then show stress and excitement and experience some violent movements before they become unconscious after an average delay of 26 seconds (Hoenderken, 1978, 1983; Leach, 1978).

Von Mickwitz and Leach (1977) considered that the carbon dioxide stunning of pigs at four EC slaughterhouses was adequate. They ranked the process at 4.0.

Rowsell (1979b) visited one Canadian slaughterhouse where pigs were being stunned with carbon dioxide. Most, but not all, of the pigs were rendered unconscious, with loss of the blinking reflex. For a few pigs, the time from stunning to bleeding was more than 30 seconds. Rowsell commented, however, that the method was uniform and could not be abused in the manner possible with electrical stunners.

Religious Slaughter

In slaughter carried out under Jewish or Islamic law, the question of humaneness is tied to the questions of how painful the cutting of the animal's throat may be, and how quickly the animal loses consciousness. Proponents contend that the cut is painless when made properly (e.g., Homa, 1971), and Grandin (1980b) concluded that the Jewish and Islamic methods "are probably the least painful techniques of throat-cutting for conscious animals, provided a humane restraining device is used."

Animals remain conscious for several seconds after their throats have been cut. This time varies from 3 to 10 seconds for sheep to up to 100 seconds for calves. Hormone studies show that the procedure induces severe stress (Grandin, 1980b). Various observers have also pointed to the stress induced by the way the animals are restrained prior to killing.

Pre-Kill Treatment

The treatment of animals prior to stunning and bleeding is a major area of concern in slaughterhouse operations. Animals are taken from their familiar surroundings, forced to climb ramps into trucks, mixed with unfamiliar animals in the trucks or later, shipped by truck, unloaded by ramp, confined in holding pens, and then walked to crowding pens and into the stunning pen. Furthermore, several animals may be in the stunning pen at the same time. (This practice may be an advantage in the case of sheep, which may be less stressfully handled in a group; Kilgour, 1976, cited in Grandin, 1980c; Kilgour, 1978.) That all of these events may be stressful to the animal has been shown by the increased levels of stress hormones that have been measured in the blood. (See Grandin, 1980d.)

Comparison with Harp Seal Hunt

The slaughterhouse methods can be compared in detail with the clubbing of harp seal pups on the basis of the same considerations on which the various seal hunts were compared.

Pre-Kill Stress

Harp seal pups on the ice experience little or no pre-kill stress but considerable stress occurs in all slaughter operations in moving the animals to the slaughterhouse, holding them and then moving them to the stunning pens.

Killing Method When Properly Practised

Clubbing a harp seal pup, when carried out properly with proper equipment, will produce instantaneous unconsciousness, as will mechanical, manual and electrical stunning of animals to be slaughtered. Carbon dioxide stunning and the Jewish slaughter method do not produce instantaneous unconsciousness, and the animal may endure stress or pain prior to lapsing into unconsciousness.

Frequency of Improper Killing

The frequency of improper killing of harp seal pups was reviewed in the section entitled "Comparative Humaneness of Methods of Killing Seals." Since 1968, the frequency of unfractured skulls has usually beeen recorded as less than 10%, but problems have arisen, most notably during hunts by landsmen.

The frequency of improper killing at slaughterhouses varies greatly among establishments according to such features as slaughterhouse design, equipment maintenance and employee attitudes. Many of the Canadian and EC slaughterhouses inspected by Von Mickwitz and Leach (1977), Rowsell (1979b), and Grandin (1982) appear to have been responsible for improper killing of numerous animals. In particular, in a number of plants using electrical or carbon dioxide stunning, the interval from stunning to bleeding was too long, and most or all of the animals would have regained consciousness prior to bleeding. In the Jewish slaughter method practised in the United

States, approximately 30% of the animals are not killed properly according to the religious tenets (Grandin, 1980b).

Consequences of Improper Killing

When a harp seal pup is not rendered unconscious by the sealer's first blow, it can be quickly clubbed again. The skull is usually fractured or crushed with one or more blows, thus rendering the seal unconscious. If the seal were not unconscious as a result of the blow or blows, it would rapidly lose consciousness when exsanguinated (Karstad, 1970).

All the slaughterhouse methods of stunning (mechanical, manual, electrical and carbon dioxide) can be repeated quickly if necessary. Slaughter animals that are improperly stunned manually can quickly be clubbed again in the same way. Improper mechanical stunning can be quickly remedied if a second captive-bolt pistol is kept ready for use. Electrical stunning can be quickly repeated if the condition is recognized, although in some cases of improper electrical stunning, the animal may be paralyzed while remaining conscious and will retain consciousness until it is bled if the condition is not recognized. Animals that are not properly stunned with carbon dioxide can be rerouted through the stunning chamber. All slaughter animals that are not properly stunned prior to bleeding will quickly lose consciousness when they are bled; unconsciousness will probably occur in less than one to three minutes.

Stress to Other Animals

The female harp seal may suffer distress from being present when her pup is killed or on returning to find that it has been killed. The extent and importance of such stress is not known.

Slaughter animals will experience stress if there are more than one in the stunning pen at the same time. This reaction applies particularly with cattle and pigs. The stress will probably be increased further if the animals are not restrained within the stunning pen. Stunning pens that hold several animals have been commonly reported in the inspection reports of Von Mickwitz and Leach (1977), Rowsell (1979b) and Grandin (1982). The stress caused an animal by seeing another animal stunned would not last long, however, as the observing animal would presumably soon be stunned also.

Summary

Clubbing of harp seals is as humane as, or more humane than, the methods used in slaughterhouses when both methods are carried out properly. The frequency of improper killing appears to be generally lower for harp seals than for the majority of animals in the slaughterhouses inspected.

The pre-kill stress of harp seal pups is very much less than that of slaughtered animals. The only other animals affected are the female harp seals. Any distress to these animals may be compared to the distress caused to female farm animals when their offspring are removed for later slaughter. It seems that in farm animals, which have a much longer period before weaning than harp seals, the parent-offspring bond may be stronger and the stress correspondingly greater.

Overall, the clubbing of harp seals by sealers from the large vessels appears to be as humane as, or more humane than, the killing methods practised in most slaughterhouses. The situation is less certain when hunts have been conducted by landsmen, and the incidents of improper killing have been more common.

Some observers, familiar with slaughterhouse operations, who have assessed the humaneness of the harp seal hunt, have similarly considered it to be as humane as, or more humane than, the killing of food animals in slaughterhouses (Hughes, 1967; MacLeod, 1967; Jones, 1968; Platt, 1970; Jotham, 1978; Taylor, 1979). MacLeod, for example, stated that:

> *There is no doubt that the killing of whitecoat harp seals in the Gulf of St. Lawrence by Canadians is as humane as the average slaughtering operation, and more humane than many, particularly those where there are no provincial humane slaughter laws.*

Even though this comparison may imply that the degree of humaneness in the harp seal hunt is about the same as that in most of the slaughterhouse operations which are implicitly accepted by the public, it should not be taken to mean that all is entirely well in this whole matter. Rowsell (1985) makes a telling point: "There is not a single area where animals are killed where problems in producing instant unconsciousness do not exist." As long as seal hunting continues, therefore, there should be no relaxation of efforts to maintain and improve on standards of humaneness.

Big Game Hunting

Large numbers of big game animals are shot each year in North America. Hunters took 2,143,210 deer in the United States in 1976 (Langenau and Aho, undated). Further inquiries suggest that the annual sport harvest in the United States and Canada during the period 1980–1985 was at least of the order of 65,000 elk, 65,000 moose, 35,000 antelope, 35,000 bears, 30,000 caribou, and 5,000 mountain goats and sheep.

Most of these animals are shot with modern rifles, but there is a significant harvest of deer that are shot with bow and arrows. Some states and provinces also permit hunting with shotguns, pistols, muzzle-loading rifles, muzzle-loading pistols, crossbows, and/or hand-thrown spears.

Humaneness of Big Game Hunting

The questions concerning the humaneness of big game hunting centre mainly on how many big game animals are not killed instantly, and how long such animals suffer. There is little information available on these questions for big game animals other than deer. Calculations of the numbers of deer that are shot but not recovered have ranged widely from 3% to 64% of the total numbers of deer legally shot, whether recovered or not, with an average of about 24% (Losch and Samuel, 1976; Wegner, 1981, 1985). These percentages of unrecovered deer are different from the percentages of deer that are wounded. They include deer that are wounded and survive; deer that are wounded and die at that time or later, but cannot be found; and deer that are killed and are found, but then abandoned for some reason.

The Royal Commission has been unable to find any useful information on the proportion of unrecovered deer that ultimately die of wounds from rifle fire, but one worker concluded that 26% of deer wounded by arrows died, possibly months later (Herron, 1984, cited in Wegner, 1985). In another study 11%–15% of the deer population was estimated to be recovering, or to have recovered, from wounds (Langenau, in press, cited in Wegner, 1985).

Comparison with Shooting of Seals

The rates for unrecovered deer seem generally to be comparable with those for open-water seal hunts, but higher than those for hunts on the ice. A

lower rate of unrecovered seals might be expected on the ice, since there the hunter would more often have a clear view of the seal and frequently a chance of a second shot if a seal were wounded. In the water, on the other hand, the seal may be seen only briefly when it comes up to breathe, and when hit it often sinks and is unrecoverable.

While there are no good data, it also seems likely that for several reasons, the proportion of lost seals which are wounded rather than killed is lower than it is for deer. Wounded seals must surface to breathe and so may provide a chance for a second shot, while a wounded deer, if not too badly hit, may rapidly leave the place where it was shot. Seals killed outright will often sink, while a dead deer may be relatively easily found. Moreover, since seal hunters generally depend on their kill for subsistence or cash income, they are likely to have a higher standard of expertise and exercise a higher standard of care than deer hunters.

These reasons seem to suggest that in shooting seals, both on ice and in open water, the proportion of animals hit which are wounded and escape rather than being killed is lower than it is in most deer hunting. Since it is the incidence of wounding which is the critical factor in assessing the humaneness of any hunting with long-range shooting, it can be tentatively concluded that most hunting of seals by shooting is more humane than is the widely accepted hunting with firearms of other large mammals on land. While this conclusion seems consistent with what is known of the various hunts, it is based on limited and indirect observations.

Summary

Criteria of Humane Killing

1. The main requirements for killing humanely are:

    - The animal should be rendered unconscious as nearly instantaneously as possible.

    - Death should intervene rapidly thereafter, without the animal regaining consciousness.

    - The animal should undergo as little stress, pain or panic as possible before being killed.

- Other animals in the vicinity should be caused as little stress or panic as possible.

Clubbing of Harp and Hooded Seal Pups

2. Until 1966, when the seal hunt was first widely examined, the standard of killing methods seems to have been poor, and much cruelty was probably inflicted. Over the next few years the standard rose rapidly, and there has been some further improvement since then. This improvement has resulted from a tightening of the regulations, more thorough enforcement, and programs of sealer education. These administrative developments have taken place largely in response to recommendations of observers and their sponsoring bodies.

3. The key stipulations of the current regulations require that:

   - the animal be struck with an approved club so that the skull is crushed;
   - the sealer check that the animal is unconscious; and
   - the animal be exsanguinated (bled) immediately after clubbing and before skinning.

   These procedures, if properly carried out, will ensure that the animal is killed humanely.

4. Most qualified observers appear to be satisfied that in general, all but a very few pups are killed in a humane manner. The precise proportion of pups not properly killed cannot be determined, since such killings occur patchily. A few observers consider that the hunt can never become acceptably humane.

5. In recent times the most serious incident of unsatisfactory killing took place in 1981, when the ice brought seals very close to Prince Edward Island. Large numbers of untrained, ill-disciplined and poorly equipped men took part in a hunt in which many seals were undoubtedly killed in a cruel manner.

6. It is generally accepted that the pups undergo little or no stress of any kind prior to being killed.

7. The evidence relating to stress to mother harp seals is conflicting, but probably only a small proportion are distressed when the pup is killed; many retreat to the sea when the sealer approaches. Further regulatory changes, such as prohibiting the killing of pups if the mother is actively defensive, may be desirable. For the hooded seal the bond is much stronger, but it appears to exist only during the nursing period, and nursing lasts only a few days.

8. Very few seal pups are killed by being thrown into the water or crushed by vessels going through the ice.

Clubbing of Northern Fur Seals

9. Driving the animals to the killing grounds on the Pribilof Islands causes them some degree of stress, and in this respect this hunt is inferior to the Canadian hunt for whitecoats. When properly carried out, the method of killing itself is as humane as that used in the Canadian harp seal hunt.

Shooting

10. Provided that sufficiently powerful ammunition is used, or that the animal is hit in the head, death will be virtually instantaneous. In many shooting operations a large proportion of the animals are instantly killed.

11. Use of small-calibre low-powered ammunition causes a high incidence of wounding unless shooting is very accurate, but prohibiting the use of this type of ammunition could create economic difficulties in some aboriginal communities.

12. Use of shotguns to hunt seals must lead to many animals being wounded, unless the gun is loaded with a solid projectile, and is at least 20 gauge.

13. Where animals are shot in the water, about 10%–50% are not recovered. What proportion of these animals are killed outright, and what proportion are wounded and either die later or recover is not known. It does not necessarily follow that the proportion of animals wounded is greater when the loss rate is greater.

14. Harp and hooded seals are shot both in the water and on the ice from small vessels (longliners) and large vessels. Prior to 1966, a high proportion of wounded animals was observed, but conditions have improved more recently. The present practice of placing a fisheries officer on each large vessel is to be commended.

15. The arctic hunt, mainly by Inuit, for ringed and some bearded and harp seals, is conducted principally by shooting. When seals are shot on the ice, the rate of accuracy, and therefore of instantaneous killing, seems high, although the recent use of snowmobiles may have reduced it somewhat. When seals are shot in the water in summer, the loss rate may be high, but the wounding rate cannot be assessed.

16. In general, the standard of humaneness in the arctic hunt seems quite high. Much official supervision is probably not possible, but the traditions of the people seem to tend to promote satisfactory standards.

17. In some communities seals are deliberately wounded to facilitate their recovery. This practice must lead to much suffering and should be prevented as far as possible.

18. Grey seals have been hunted and killed, mainly by shooting, to control numbers for the benefit of the fishery; this practice has been carried out both by government hunters on the breeding grounds and by fishermen operating under a bounty scheme. On land the wounding rate is low; in the water the loss rate is high (up to 76%), although there are no comparative data on wounding rates.

19. Harbour seals have been subject to both bounty hunting and culling. Loss rates of adults are quoted at 35%–50%, but pups were generally retrieved.

20. Until 1968, Steller sea lions were hunted to control numbers. Adults were shot both in the water and on land. They are said to be hard to kill, and the wounding rate was high. It was suggested that the most humane way of culling sea lions would be by shooting pups on land.

Netting

21. Netting is used to take harp seals along the lower north shore of the Gulf of St. Lawrence, and on the Labrador and eastern Newfoundland

coasts. The numbers taken in this way are small compared to the kills by clubbing and shooting. Some ringed and harp seals are also netted in the Arctic.

22. Netting is a very inhumane way of taking seals. Seals do not drown in the nets, but continue to struggle until the oxygen in their blood is used up. This process may take a considerable time, and the animals remain conscious until the end.

Other Methods of Killing

23. Traditional killing methods used in the Arctic, probably now obsolescent in many places, make use of harpoons and seal hooks in breathing holes. Both devices probably cause considerably more suffering than the practice of shooting or clubbing.

24. Use of the navy and air force to kill sea lions, as has occurred on the coast of British Columbia, is clearly objectionable, and the Royal Commission assumes that such arrangements would not be contemplated in the future.

25. Poisoning seals has been tried only experimentally in Canada. It should not be considered further.

Experimental Methods of Killing

26. The shot pistol designed by Hughes for killing harp seal pups appears to be humane and less repugnant than clubbing. It is probably safe to use, but it requires further testing under field conditions. If it is found to be satisfactory in the field, its use should be considered in the event that seal pups of any species are to be killed in future.

27. None of the other methods tested gives promise of meriting further examination.

Killing in Slaughterhouses

28. Very large numbers of animals are killed in slaughterhouses for human food. Methods used are:

- mechanical and manual stunning;
- electrical stunning;
- carbon dioxide stunning;
- religious slaughtering.

Clubbing of seals is about as humane as mechanical, manual or electrical stunning, when all methods are properly used. The average incidence of errors in slaughterhouses seems to be similar to, or greater than, that which occurs in the clubbing of harp seals under good conditions.

29. In general, the level of both pre-kill stress and stress on other animals present is considerably higher in slaughterhouse operations than in most Canadian seal hunts.

30. Shooting of seals may often be less humane than slaughterhouse operations because of the relatively high proportion of animals wounded.

Big Game Hunting

31. Large numbers of deer and other big game animals are killed annually in North America. The chief problem relating to humaneness in this type of hunting is the proportion of animals wounded.

32. The most relevant comparison to seal hunting is that of the shooting of deer. The proportion of seals not recovered on the ice appears to be lower than the usual proportion of deer shot and lost, and there is likely to be a similar or greater difference in the proportion of animals wounded. In open water the loss rate seems about the same as in deer hunting, but the proportion of animals wounded is lower in the seal hunt.

33. The Royal Commission therefore tentatively concludes that deer hunting and possibly other forms of big game hunting are less humane, as judged by the proportion of animals wounded, than the seal hunts carried out by long-range shooting.

Conclusions

1. Judged by the criteria of rapidity of unconsciousness and particularly the absence of pre-slaughter stress, the clubbing of seal pups is, when properly performed, at least as humane as, and often more humane than, the killing methods used in commercial slaughterhouses, which are accepted by a majority of the public.

2. The most serious recent failures to meet satisfactory standards of humaneness in the clubbing of seal pups have occurred when ice carried seals unusually close to shore, where they were accessible to inexperienced and ill-disciplined landsmen.

3. If killing of seal pups of any species is ever deemed necessary, the special pistol developed by Hughes may prove to be more humane and less repugnant than clubbing. It is probably safe to use, but requires further testing under field conditions.

4. Shooting seals in Canada for subsistence or commercial purposes is generally more humane than the shooting of animals for sport, except that

    - the practice of deliberately wounding seals in order to facilitate recovery must lead to considerable suffering; and

    - the use of small-calibre low-power ammunition can cause a high incidence of wounding unless shooting is very accurate.

5. Catching seals in nets unavoidably causes slow and probably painful death.

6. No methods of killing which have come to the notice of the Royal Commission, other than clubbing and shooting, achieve acceptable standards of humaneness.

Recommendations

Killing of Seal Pups

1. Given that taking of harp seal pups continues (but see the Royal Commission's recommendations in this matter, Chapter 12), the Department of Fisheries and Oceans should make every effort to ensure that if the seals are likely to be easily accessible from the shore, all sealing in the area is effectively prohibited.

2. Consideration should be given to requiring by regulation that a sealer shall not attempt to kill a pup if its mother shows aggressive actions or attempts to defend the pup.

3. If seal pups of any species are to be killed in the future on the breeding grounds (e.g., as a measure of population control), further tests of the Hughes pistol to provide an alternative to clubbing should be undertaken under operational conditions.

Shooting of Seals

4. Discussions should be held with sealing communities with a view to gaining acceptance of the use of those types of rifle ammunition that ensure a high proportion of instantaneous kills under the conditions normally encountered in hunting each species of seal.

5. Discussions should be held with sealing communities with the aim of making clear that the practice of deliberately wounding seals to facilitate recovery is not condoned, and of finding ways to reduce the practice as far as possible.

Netting of Seals

6. The government should take action with a view to phasing out the netting of seals, as rapidly as possible, in those communities which now rely largely on this method to take harp seals both for subsistence and to provide a substantial part of their income. Netting of seals in other areas should be prohibited immediately.

Other Killing Methods

7. No new methods of killing seals for purposes of either harvesting or population control should be used in Canada unless they are clearly demonstrated to be acceptably humane.

Culling Operations

8. Reduction in numbers of Steller sea lions, if it proves necessary, should be achieved as far as possible by shooting pups on land rather than by shooting adults.

General

9. There should be no relaxation of the efforts to maintain and improve the standards of humaneness in all aspects of the various seal hunts. The conclusion that clubbing and shooting, when practised efficiently, are at least as humane as the general levels of slaughterhouse killing and big game hunting respectively should not be allowed to promote any sense of complacency.

Appendices

Appendix 20.1. Canadian Government Regulations re Methods of Killing

In 1966, the weapons that could be used to kill seals were restricted to clubs, gaffs or rifles, with the exception that nets could be used by local residents in the northern Gulf and at a portion of the Front. (Sealing with longlines had been prohibited in 1964.) Gaffs were prohibited as killing weapons in 1967, but shotguns firing slugs were permitted. Hakapiks, when used by sealers from large vessels, were permitted at the Front in 1976, and in the Gulf in 1979. Specifications for clubs were established or amended in 1964, 1966, 1967 and 1982; those for gaffs in 1966; those for hakapiks in 1976 and 1977; those for rifles in 1966 and 1967; and those for shotguns in 1967.

In 1967, the regulation was introduced that seals could be struck only with a club – though hakapiks were later permitted – and then only on

the forehead. It was required in 1977 that all hooded seals shot must be struck with a hakapik, and in 1978 it was required that all sealing vessels must carry a club or hakapik. In 1980, seals killed with a club or hakapik were required to be struck three times or until the skull was crushed. In 1984, it was required that when a seal was clubbed, its skull must be crushed prior to skinning.

Skinning of a seal before it was dead was prohibited in 1964. In 1967, a new regulation was introduced to the effect that "No person shall hook, commence to skin, bleed, slash or make any incision on a seal with a knife or any implement until the seal is, without doubt, dead." The phrase "without doubt" was removed in 1976. In 1978, a seal was considered to be dead (and hence permitted to be bled, skinned, and so forth) if it "(a) is glassy eyed; (b) has a staring appearance; (c) has no blinking reflex when the eye is touched; and (d) is in a relaxed condition." The regulation that once a seal was dead, it must immediately be bled by cutting the blood vessel to the fore-flippers was introduced in 1979. Amendments enacted in 1980 prohibited any sealing group from stockpiling more than 10 seals that had not been pelted.

The use of aircraft in the seal hunt for any purpose except locating seals was prohibited in 1964, for all areas except the main part of the Gulf. The exemption relating to the Gulf was removed in 1970. Night sealing was prohibited in 1967, and adjustments to sealing hours were made several times thereafter. Out-of-season taking of seals by landsmen was restricted to local residents in 1971; and in 1977, all sealers operating from shore or in small boats (landsmen) were restricted to taking seals in the waters off the part of the province in which they resided.

In order to enforce the regulations and to control the sealers on the ice, regulations were introduced requiring licences for sealing vessels (1961), aircraft (1964), vessels over 30 feet (9 metres) in length (1964), sealers from vessels requiring licences or from aircraft (1964), and all individual sealers (1966). Modifications and restrictions to the licence requirements were introduced from time to time thereafter. Fisheries officers were given the power, in 1967, to suspend a sealer's licence immediately for up to 30 days, and sealers were required to wear visible means of identification. Masters of ships and pilots of aircraft were made responsible, in 1967, for the killing methods used by their crew members or passengers. In 1976, criteria were established for experienced sealers and assistant sealers, and assistant sealers were restricted to working under the supervision of an experienced sealer and to killing only under his direct supervision.

Appendix 20.2. Norwegian Regulations, 1968–1970

The Norwegian sealing regulations that were in effect in 1968 (as reported in Søgnen, 1968) required the sealers to use humane methods of kill and to strive to prevent unnecessary suffering. Seals could not be taken by line, net or trap; they could be killed only with a hakapik, a club or a rifle. Seals were to be struck with the hakapik or club only on the head. The fastening of hooks to live seals was forbidden, as was the skinning of a seal before it was certainly dead. In 1970, as reported in Platt (1970), seals could be clubbed with a heavy iron hook, but not with a club. When a seal was shot, the skull was to be crushed immediately with a hakapik. Seals had to be dead before they could be hauled aboard ship. In 1964, when the Canadian fishing zone was extended to 12 nautical miles offshore, and in 1977, when Canadian jurisdiction was extended to 200 nautical miles offshore (including the waters of the Front), the activities of Norwegian sealers within those respective areas became subject to the Canadian Seal Protection Regulations.

Appendix 20.3. Reactions of Female Seals to Loss of Young

Observations of harp seal mothers and pups have been made at various times during the short nursing period of eight to 12 days (Lavigne, 1979; Stewart and Lavigne, 1980). The point of time within the nursing period at which the observations were made appears to have affected the reactions of the females observed (Quine, 1985).

Some females leave their young and enter the water when a sealer approaches. Estimates of the numbers that do so have varied from the high proportions of 90%–95% (Fischberg, 1969) and 85% (Taylor, 1979) to the low numbers of Jotham (1978) who reported that most females that were on the ice when the pup was approached remained to defend it. Some of the females that remained to defend their pups soon left them or were easily chased away (Jordan, 1978); but some seals showed strong aggression in protecting their pups. Johansson (1967) reported that 1% or fewer were strongly aggressive; Rowsell (1980) reported aggression by females for 24% of 106 pups that were checked. Most aggressive females have been first-time breeders (Johansson, 1967), but on at least one occasion an older female was observed to have been quite aggressive (Walsh, 1978). Females in an unhunted whelping patch were more aggressive toward humans than those in hunted patches (Ronald, 1975).

The reactions of females towards the carcasses of their pups have also been quite variable. Rowsell (1979a) noted a number of females in the vicinity of carcasses; the females seemed to be oblivious to the presence of the carcasses. Some seals returned to sniff carcasses and then left quite quickly (Johansson, 1967); one seal that had been very aggressive in defending her pup when it was clubbed but not pelted paid little attention to the carcass after it had been pelted (Rowsell, 1978). Another female was observed to sniff a carcass that was not that of her pup (Hughes, 1978a; Scott, 1978). Other females have been aggressive in defence of the carcasses of their pups (Simpson, 1966, 1967a) or have remained with them for a considerable time (CVMA, 1980). Quine (1985) estimated that 4%–5% of the females would defend their pups against a sealer or would return and lie over the skinned carcass.

The strength of the pair bond during the short nursing period and the distress that the female may feel on the loss of her pup are not known. Some observers have been of the opinion that the females may indeed suffer (e.g., Fischberg, 1969; Taylor, 1979), whereas others have believed that the females were not much affected (Maton, 1969).

Seals produce milk only under the stimulation of suckling (Ronald, 1970), and females that lose their pups before weaning will quickly cease to lactate. Cessation of milk production will probably be quickly followed by mating (Lavigne, 1979; Ronald and Dougan, 1982).

One suggestion for eliminating any stress that the female harp seal may suffer when her pup is killed is to prohibit the taking of any seal pup when the female actively defends it (e.g., Walsh, 1966; CVMA, 1980). Although sealers sometimes refrained from taking the pups of aggressive females (e.g., Maton, 1969), this recommendation was never required by the regulations. Females that leave their pups when a sealer approaches, or that were absent when he approached might still suffer distress if this suggestion were to be implemented.

A second possible method of ensuring that females do not suffer distress at the killing of their pup would be to delay the hunt until most of the pups have been weaned and the mothers have left them. Hughes (1985b) suggested that the ideal time to kill harp seal pups was immediately after weaning. Because of differences in timing of the pups' births, this practice would probably involve taking many older seals that had moulted (beaters) and were more vigorous and active than newborns (Hughes, 1985a). In consequence, it would alter the nature of the seal hunt to some extent. The practicality of making such a change would have to be evaluated.

The distress that may be suffered by the female hooded seal on the loss of her pup has received much less consideration than has that of the harp seal. Rowsell (1975) noted a female that did not make any frantic search for the pup, but instead chased the male into the water. Until 1977, it was customary to shoot the female prior to taking the pup. Since that time none of the observers have commented on the reactions of female hooded seals to the loss of their pups. Greendale (1985) stated that in his experience female hooded seals have shown more attachment to their young (after they have been either killed or removed during the course of tagging) than have female harp seals. Hooded seals have a very short nursing period which averages four days (Bowen et al., 1985) after which the seal pup is left alone. A possible means of avoiding distress to the female hooded seals on the taking of their pups would be to delay the start of the taking of hooded seal pups until most have been weaned (e.g., Reeves, 1977). Again, the practicality of making such a change in timing would have to be evaluated.

Appendix 20.4. Tear Production in Seals

Mammals (and all terrestrial vertebrates) possess a number of glands that provide secretions to moisten the eyeball and, to some extent, to keep it aseptic. These glands are hidden in the eye socket in various positions depending on the species. The most important glands are the lachrymal glands, the secretions of which are called "tears" in humans, and the Harderian glands. The Harderian glands provide a somewhat more viscous lubricating fluid and are often considered to function so as to cushion the eyeball (Eglitis, 1964; McEwen and Goodner, 1974).

Because the surface of the eyeball, particularly the transparent area of the cornea, cannot be allowed to dry without risking serious problems, both glands constantly secrete fluid. In terrestrial species this applies especially to the lachrymal gland. In terrestrial mammals (including humans) each eye possesses a nasolachrymal duct or tear duct in the lower lid, normally in the inner or medial corner. This duct drains the constantly secreted fluids into the nasal cavity (McEwen and Goodner, 1974).

If, for any reason, there is cause for an abnormal increase in tear production, such as a breeze in the face or some foreign irritant in the eye, the tear ducts are unable to handle the drainage of the extra fluid that is produced mainly by the lachrymal glands, and the excess tears dribble or flow down the face. If there is an abnormal blockage of one or both tear ducts, even the normal secretions cannot be drained away, and the result will be tears dribbling out of the eyes.

Seals possess no nasolachrymal ducts. The Harderian glands are particularly large, whereas the lachrymal glands are relatively small (King, 1983). When seals are in the water, where they spend most of their lives, the Harderian glands probably play the more important role, and the viscous fluid they produce would minimize the frictional effect of the flow of water against the cornea.

When seals are on land or on ice and their fur has dried out, tears can always be seen dribbling from their eyes, since even the normal lubricatory secretions, which in seals almost certainly come mainly from the lachrymal glands, cannot be drained away. This is true of both hunted and undisturbed seals. When there is a wind blowing, the tears that would normally dribble down the front of the face not only increase in volume to protect against drying damage to the cornea, but are also blown back around the eye area and the side of the head so that large patches of wetness constitute a normal phenomenon around the eyes.

Whitecoat harp seal pups readily display normal dribbling of tears from the eyes, but their long white fur usually prevents the large wet patches from forming around the eye area. (These patches are typical of adult harp seals with their short flat hair.) The pups' tears dribble in large droplets down the front of the face. When there is no wind and the flow of secretions is minimal, pups often shut their eyes momentarily. They may do this involuntarily or voluntarily if, for example, they are touched by a person. This reaction squeezes tears out of the eyes, as the tears cannot go down a non-existent tear duct. This response does not mean, however, that there is a sudden increase in tear production.

Humans are unique among mammals in producing emotional or psychic tears (McEwen and Goodner, 1974). Crying, laughter, and emotions such as anger, fear, sadness or joy cause the lachrymal glands to respond with increased secretions, and the effect is similar to that caused by wind or an irritant: the ducts cannot drain all the flow, and tears result.

No evidence has been found that any mammal other than man weeps emotional tears, and in particular there is no evidence that seals do so. The "crying" of a lonely puppy, for example, is not accompanied by tear production. Walls (1942) stated that bears weep "psychic tears", but he did not elaborate or provide any reference, and the Royal Commission is unaware of any substantiation of his statement.

In a large whelping patch of harp seals or any seal species breeding in large gatherings, there is a constant cacophony of sound, mainly from vo-

calizing pups, but also from answering parent seals. Much of the ability to locate and recognize in mother-pup relations is based on the uniqueness of the individual calls of the mothers and pups (Evans and Bastian, 1969; Petrinovich, 1974). Once physical contact has been made, final recognition is olfactory, based on the uniqueness of the odour of the amniotic fluid on the pup's fur (Bartholomew, 1959).

There is no basis for labelling these normal vocalizations weeping, with accompanying tears of fear, in the presence of a hunter. The cries of the pups among a patch being slaughtered are no different from their normal sounds, although there is sometimes a snarling response as a person approaches closely. Nor is there any change in the normal secretion rate of the tears (Fisher, 1985).

Appendix 20.5. Shooting of Arctic Seals

When harp seals first arrive in the Arctic in June, after migrating from the south, the thickness of their blubber is at a minimum, and most will sink when shot (Haller et al., 1967). As they feed through the summer, there is a decrease in sinking loss. During break-up there was a 65% loss of 46 seals shot; during the open-water period in July there was a 50% loss of 34 seals shot; and during the open-water period in August there was a 37% loss of 38 seals shot (Haller et al., 1967). By October harp seals were reported to float when killed.

Davis et al. (1980) have reviewed the losses of ringed seals by sinking. Losses depend on the type of hunt and on the time of year. Ringed seals have less blubber thickness and less buoyancy in May and June during the moult and are most likely to sink at this time (McLaren, 1958). The water salinity and water density are reduced during break-up in June and July, and this factor also leads to increased sinking (McLaren, 1958). Losses of ringed seals in hunts on ice, at the floe edge or at break-up (February–July) ranged from 7.5% to 23.1%, with one high value of 47.4% (Davis et al., 1980). Losses of ringed seals in open-water hunts ranged from 27.9% to 52.4% in June and July, and from 3.6% to 15.9% in August and September (Davis et al., 1980).

The high losses from sinking considerably influence the methods used to shoot seals and the humaneness of these methods. Hunting techniques in the eastern Canadian Arctic vary with the time of year and the ice conditions. In winter ringed seals are taken at their breathing holes (Haller

et al., 1967; Wenzel, 1981). The seal is shot from point-blank range and is unlikely to be missed, although some wounded seals may escape (Haller et al., 1967).

In spring ringed and bearded seals begin to haul out on the ice, and two techniques are used to hunt them. Using the first technique, the hunter stalks a seal on foot until he is within 90 metres of the seal (Haller et al., 1967). He then supports the rifle for a careful shot and shoots the seal in the head. Accuracy is high, and the killing shot prevents the seal from escaping to the water. Loss of bearded seals can, however, be high at this time (Davis et al., 1980). A second method that has become more common in recent years is to stretch a white screen across the front of a snowmobile and drive the snowmobile toward a seal that is hauled out (Wenzel, 1981). The seal is usually slow to locate the source of the sound, and the hunter can frequently approach close enough to shoot the animal. With the snowmobile technique, almost twice as many shots were fired per seal killed as were fired with the technique of stalking on foot (Wenzel, 1981), and possibly more seals were wounded.

At break-up, seals may be shot in the water by hunters on the ice, who then launch a small boat to retrieve the carcass (Haller et al., 1967). There is a higher percentage of hits during early break-up, when shooting is at closer range. Some ringed seals may sink at this time, and most harp seals will sink. Hunters in the Cumberland Sound area have been reported to shoot to wound the harp seals in the nose or throat (Haller et al., 1967). In this way the seal is weakened from loss of blood and is less able to dive, and the hunter can get sufficiently close to shoot it fatally and to retrieve it before it sinks.

During the open-water period seals are shot in the water by hunters in boats (Haller et al., 1967; Wenzel, 1981). Haller et al. (1967) describe a technique of hunting ringed seals in which hunters shoot at them as soon as they surface in order to force them to dive and to resurface more rapidly than is normal. The hunter will try to anticipate where the seal may surface and will turn off the motor for a more accurate shot. In northern Labrador, where the water is very clear and hunters can see the bottom, seals that sink are retrieved with a cod jigger (Andersen, 1985).

Because harp seals sink so quickly, they are hunted in Cumberland Sound during the early open-water period only if they are close to the boat (Haller et al., 1967). Later in the summer, hunters more frequently chase harp seals and shoot them from a moving boat. Smith and Taylor (1977)

have noted the characteristic "porpoising" of harp seal groups when they are chased in open water; this behaviour would make them difficult targets, and in consequence, the authors have suggested that wounding rates must be high.

Bearded seals are also hunted during the open-water period, but they sink very quickly. They may be intentionally wounded with a shot to the back or belly so that hunters can approach close enough to harpoon and then kill them (McLaren, 1958; Smith and Taylor, 1977; Davis et al., 1980). Wenzel (1981) described an open-water method of hunting bearded seals in which at least two boats formed a wide circle to prevent the seal from getting beyond them. Each time the seal surfaced, the hunters immediately fired at it to force it to dive. When it was exhausted and could not dive, the boats closed in and the seal was killed. Bearded seals were also shot when they hauled out onto ice pans during the open-water period (Wenzel, 1981).

At Lake Melville, Labrador, hunters shoot ringed seals on the ice during the haul-out period (Boles et al., 1983). Seals must be stalked sufficiently closely to ensure a killing shot. Hunters aim for the head to ensure a clean kill and to prevent damage to the pelt. Many hunters prefer small-calibre rifles because of the less expensive ammunition, and because the bullet is less likely to damage the pelt. Ringed seals are also shot in open water on a year-round basis, in tidal channels near the mouth of Lake Melville (Boles et al., 1983).

Similar hunts (breathing hole, haul-out, ice edge and open water) are practised in Greenland, although snowmobiles and, in some areas, motorboats are not used (Kapel, 1975).

On the basis of the few statistics available and of the descriptions of the hunting techniques used, Miller et al. (1982) have suggested that loss rates were lower in Greenland. The custom followed in the Thule area during the breathing-hole hunt is to shoot the seal and immediately to launch a harpoon down the breathing hole to retrieve it (K'ujaukitsoq, 1985). In the Upernavik area, harp seals were intentionally wounded with shotguns so that they could be retrieved before they sank, and ringed seals were shot at repeatedly as soon as they surfaced to exhaust them and make their final kill and retrieval easier (Haller, 1978).

Appendix 20.6. Netting of Harp Seals

On the lower north shore of the Gulf of St. Lawrence, seal nets are set out in various configurations (Beck, 1965; Baril and Breton, undated). In many places they are set across passages either between islands and the mainland or between islands. In some places a series of nets is extended out from shore to form a trap that is difficult to escape from. At La Tabatière a very complex set of nets with several small inner traps is set up; the same pattern of nets has been in use there for more than 100 years (Ronald, 1982). The nets are usually hung so that the top rope is at a depth of two metres (to avoid ice) and the bottom of the net is on the sea floor (Beck, 1965). The head rope is brightly coloured. Harp seals are also caught in smaller-mesh fish traps. In this instance the seal swimming inside the trap is probably shot (COSS, 1984). The net fishery on the lower north shore has been greatly reduced in very recent years with the collapse of the market for sealskins (Sergeant, undated).

Migrating seals would try to dive under the head rope of the net (Ronald, 1982). They would then push against the mesh until they became entangled. Alternatively, they might attempt to push under the net at the bottom, only to have it cover and trap them. Few seals apparently swam over the head rope. Seals pushing against a net would cause the slack of the net to engulf them. Some would push forward against the mesh until they had a flipper through the mesh and were entrapped. Others would turn and spin, and thereby become completely entangled. Most seals were taken at night; those caught during the day were mainly seals that had been forced to dive by the harassment of being chased by boats and shot at.

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Chapter 21

The Status of Stocks of Atlantic and Arctic Seals

The myth of seals as endangered species must be dispelled (Cournoyea, 1985).

Harp Seals

Summary

Harp seals are found across the northern part of the North Atlantic; they breed in three main areas: off eastern Canada, around Jan Mayen Island, and in the White Sea off northern Russia (Figure 21.1). The Canadian herd breeds in two distinct concentrations: in the Gulf of St. Lawrence, and on the Front area to the northeast of Newfoundland. The young are born in the early spring, and the seals migrate north and northeast to spend the summer feeding in northern Canada as far as Lancaster Sound, and off west Greenland (Figure 21.2).

In the northern areas, for centuries they have been subject to a traditional hunt by aboriginal peoples, but the main commercial harvest has been of pups and some adults on the breeding grounds. Catches during the present century have been high, comprising some hundreds of thousands of animals and reaching a peak of about 450,000 in 1951. Since 1971, catches have been controlled by quotas and have fallen to 150,000–200,000 annually. In 1983, the market collapsed, and in the last three years catches have been much smaller.

A number of methods have been used to estimate the total population of seals, which is usually measured as the number of pups produced in one year; these methods include direct surveys of the breeding population from the air, tag-recapture studies, and analyses of the age composition of the catches (including survival index and similar methods). Despite the very different assumptions involved in each method, the different data sets used

Figure 21.1
Distribution of Harp Seals

Source: King (1983).

in applying the methods, and the general difficulties inherent in studying an animal that lives in a harsh and remote environment, and can only be easily observed while on the breeding ice patches for a few weeks each year, there is good agreement among the different estimates. With a few exceptions, such as those obtained from tagging results in a particular year, most estimates of pup production in recent years are in the range 200,000–600,000. When allowance is made for the bias that may arise in applying some methods, it appears that the pup production in the years close to 1978, the most recent period for which several estimates are available, was some 300,000–350,000, equivalent to a total population of animals of all ages of about 1.5–1.75 million. Allowing for a probable increase in the harp seal population since 1978, the total number of these animals at the end of 1985 was about two million.

Though this number is large, it is well below the initial number of harp seals. The harp seal stock has been seriously reduced from its size when commercial sealing began. Presumably in response to this reduction the natural population parameters are now such that the number of births exceeds the number of natural deaths, and in the absence of any hunting the population would increase. The response appears to have occurred largely through density-dependent changes in the age at which seals mature and possibly, also, in the pregnancy rate. If there were no more hunting, these parameters would presumably, as the population recovers, return in due course to their original values, and the population would stabilize at some level greater than the present one. This stable level might not be exactly the pre-exploitation level, because of possible natural changes in the carrying capacity and also because of the effect of human exploitation of fish stocks on which the seals feed. It is not known what this stable level is, but it is probably well above the present level.

The sustainable yield, that is, the difference between the numbers of births and natural deaths, will depend on the population parameters, particularly the natural mortality and age at maturity. For the more likely sets of parameters, it is believed to be about half of the number of pups born each year. If some older animals are killed, the total numbers taken will have to be reduced from the allowable catch if the harvest were taken entirely as pups. The sustainable yield for any combination of old and young seals can be calculated by taking one adult seal as being equivalent to about two pups.

Since catch quotas were introduced in 1971, catches usually have been at or below the quota levels. Quotas have probably been set at less than

the sustainable yield so that between 1972 and 1983, the total seal population has probably increased; the possibility that it has decreased cannot, however, be ruled out. If there was a decrease, the rate of decrease was low. Since 1983, the population has certainly increased. Since catches are likely to remain small, this increase, which may be about 5% per year, will almost certainly continue for some time to come.

The population figure which corresponds to the maximum sustainable yield (MSY) is not known, though it is more likely than not to be greater than the present population figure. In the context of the harp seals, however, and in view of the different objectives to be considered (few of which are primarily concerned with achieving the greatest possible yield), the MSY

Figure 21.2
Migration of Harp Seals in the Northwest Atlantic

Source: Mansfield (1967a).

level is not very significant. The critical level at which the population is so small that there is real risk of its declining to extinction, even in the absence of any more hunting, is probably only a few hundreds or fewer, and is certainly very much lower than the present level.

Though the uncertainties about the dynamics of the harp seal population are not significant in terms of assessing the species' present status, their effect increases when one attempts to project the effect of different policies into the future. It is probable that catches of about the size taken in the late 1970s would allow the harp seal population to increase, but there is a chance that they would cause a decrease, and if this decrease were allowed to continue uncorrected for a period of as long as 10–20 years, it might occasion a serious threat to the stock. It is therefore important that any future harvesting of harp seals, other than at the most trivial level, should be accompanied by a regular program of monitoring the stock and adjusting the allowable catches accordingly; the same conclusion applies also to other species of seals. If there can be significant variation in the year-to-year catches of young seals, the survival-index approach would be a suitable method of monitoring. Otherwise direct surveys would be needed. Even in the absence of large-scale harvesting, monitoring of stock abundance will be required if there is any question of an increasing abundance of seals having a serious effect on commercial fisheries.

Under the present circumstances, these discussions about future management are somewhat hypothetical. With the collapse of the markets for seal products, recent catches have been small, and there is little immediate prospect of economic conditions changing. Elsewhere in this Report (Chapter 12) the Royal Commission recommends that the commercial hunting of pups (whitecoats) should not be permitted. If this recommendation is acted on, it is difficult to see large-scale hunting of harp seals recommencing in the foreseeable future.

The stocks will therefore increase. How fast they will increase and how long this increase will continue depends on how much hunting of older seals occurs, and the dynamics of the stocks, especially the density-dependent effects. If no hunting is done outside Greenland and the Canadian Arctic, catches may be no more than perhaps 20,000–30,000, compared with a current sustainable yield, in pup units, of perhaps 170,000. The net increase is therefore likely to be the equivalent of 100,000 pups or more. Without some estimate of the ages of any seals killed, and without examining the details of the present age structure of the population, it is not possible to express this increase exactly as a percentage increase. Given a

current (end of 1985) population abundance of about two million, the increase is likely to be about 5% per year.

The current population is certainly well below the initial population abundance, and although the carrying capacity may have been reduced by the exploitation of some of the fish species on which harp seals feed, it, too, is likely to be well above the present level. It would be realistic to expect the increase to continue until the abundance is at least twice the present level, and perhaps well beyond. The information is not good enough to make useful predictions of the actual abundance in future years, since small changes in the population parameters can make a great difference. Thus, if the rate of increase is, in fact, 5%, then in 15 years the population will have slightly more than doubled (to 208% of the present number). However, if the true rate was 3% or 7%, the changes would be only 156%, or nearly trebling (to 276% of the present number). In these circumstances, and if there were any concern about the possible impact of increasing numbers of seals on the fishery, regular monitoring of the stocks would be very important.

Background

The harp seal is found throughout sub-arctic waters of the North Atlantic where it has three main breeding areas: in the White Sea, around Jan Mayen Island and off the coast of Canada. The last group is separated into two main concentrations of breeding animals which are found in the Gulf of St. Lawrence, and in the Front area to the northeast of Newfoundland. There is apparently no mixing between harp seals of the eastern and western Atlantic, but considerable mixing between animals of the Gulf and the Front.

Harp seals are gregarious animals and breed in huge concentrations. Their mating takes place shortly after pupping, and they are apparently monogamous or promiscuous, but there is no evidence of any organized social system. The young are born on the ice in late February to mid-March. In the summer the seals from the Canadian breeding grounds move north through Davis Strait, and they are found along the west coast of Greenland, and on the Canadian coast, from Hudson Bay to Baffin Island and Lancaster Sound (Lavigne, 1979).

After they are weaned, the young seals feed largely on zooplankton (mysids and euphausiids), while the older animals also eat a variety of fish (polar cod, herring and capelin, and occasionally groundfish), as well as squid. The adults apparently eat little or nothing during the breeding

season (Mansfield, 1967a). The food of harp seals is dealt with in more detail in Chapter 24.

Harp seals mature at about five years of age. They live up to 30 years or more, with a natural mortality rate of about 10% per year. Not much is known about the causes of natural mortality. Predation by polar bears, Greenland sharks *(Somniosus microcephalus)* and killer whales is believed to be low; parasitism and disease are also believed to be factors of little significance (Lavigne, 1979).

History of Exploitation

The "seal hunt" as commonly imagined by the public is the harvest of whitecoat harp seal pups in the first couple of weeks of life, on the ice fields of the Front and the Gulf of St. Lawrence. This hunt, particularly by crews of large vessels from St. John's, Newfoundland, Halifax, Nova Scotia and Norway, has accounted for the greater part of the kill in historical times, but is not the only harp seal hunt. There are similar hunts in the White Sea conducted by the U.S.S.R. and near Jan Mayen Island, conducted by Norway and the U.S.S.R. Immature and adult harp seals are also taken commercially by a variety of small-boat fisheries. In addition, subsistence hunting is important in both Greenland and northern Canada. The details of the harvest, the numbers taken, and the products (oil, fur, leather and meat) are treated in Chapter 14.

In the Canadian region, catches at the beginning of the century amounted to about 250,000 animals per year. These numbers declined during the First World War and stood at about 150,000 per year between the wars. Virtually no commercial sealing was done during the Second World War, but after 1945, Canadian sealers were joined by Norwegians. Catches on the breeding ice reached a peak of some 450,000 animals in 1951, and averaged about 300,000 a year up to 1966. In 1965, a quota of 50,000 harp seals was set for the Gulf, but a quota for the whole hunt, including the Front (then outside Canadian waters), was not set until 1971. Since then, catches have been limited by quota; subsequent to the ban imposed by the European Community (EC) and the collapse of the market, catches have been low. In 1984, only 31,000 animals were taken. Most of these were beaters, that is, animals that have moulted out of their original white fur, but are still in their first year of life; some older animals were also taken.

Estimation of Abundance

All the main methods for making a census of marine mammals, as described by Eberhardt et al. (1979), have found some application to harp seals. The abundance of the harp seal population has been estimated by four methods: direct surveys of part or the whole of the population; mark-recapture methods; the "survival index" method; and sequential analysis of the history of the population. A fifth method, analysis of catch and effort data, has not proved useful because of the nature of operations in the main season, though data from the summer season in Greenland may be useful in following changes in relative abundance. The next sections describe three methods of estimating abundance: in a single year (surveys), or over a short period (mark-recapture and survival index). The method of sequential analysis will be considered after the reasons for changes in population size.

Surveys

Harp seals can be surveyed directly when they are on the ice during the breeding season and shortly afterward, when they are moulting. The entire population is not available to be counted, but counts can be made of either breeding females or the newborn pups. The latter are not easily seen against the ice, but they show up well on photographs taken with ultraviolet light (Lavigne and Øritsland, 1974).

The basic principle of conducting a survey is simple and sound, but in practice the survey must be carried out carefully if it is to provide useful results. Given good weather (which cannot be guaranteed during the short period available for counting), the method is reliable and free from some of the errors and uncertainties inherent in other methods.

The chief problems are:

- The survey may not cover the entire breeding population. It may not be possible to survey both the Gulf and Front areas, and it is not easy to be sure that all the whelping patches in an area have been detected and surveyed.
- The females may not all be on the ice at the time of the survey.
- Some males may be present and may be counted as females.

- The survey may take place before all the pups are born or after some have died or left the ice.

All these possibilities of error, except for the third mentioned, which is likely to be small, lead to underestimates of the total population of breeding females or of pups, but the degree of underestimation is unknown and could be large if, for example, a large patch is missed. The method is therefore not attractive when an attempt is being made to obtain a single best estimate, and it has been neglected recently in favour of other methods. For other purposes, such as deciding whether the removal of 1,000 pups is likely to threaten the stock, a lower bound to the abundance is useful. The method is also the only one that does not depend on a significant harvest, and it could therefore be invaluable for future monitoring.

The published estimates of the production of pups obtained from surveys are given in Table 21.1. Confidence limits are available for only some of these estimates, and the quoted figures suggest big differences in the precision achieved by various procedures. The 95% confidence limit of ± 30% achieved by Lavigne et al. (1980) for the 1977 Front total by stratified random sampling is probably typical of most figures.

Table 21.1
Estimates of Pup Production (000s) by Different Survey Methods

Year	Gulf	Front	Total	Source
1950	215	430	645	Sergeant (1975)
1959–60[a]	150	215	365	Sergeant (1975)
1964	100 [b]			Sergeant (1975)
1967	over 30[c]			Sergeant (1975)
1970	75	150	225	Sergeant (1975)
1972	125	100	225	Sergeant (1975)
1975	46	no estimate	250	Lavigne et al. (1980)
1977	no estimate	200(+)		Sergeant (1975)

Note: A variety of different methods was used for analysis of the data, resulting in a range of different estimates. Stratified random sampling was believed to give the best estimates, which are given here.

a. Pooled data.
b. South Gulf only.
c. North Gulf only.

Mark-Recapture

The basic principle of the "mark-recapture" method is simple. (See Eberhardt et al., 1979.) Suppose that 2,000 animals are marked or tagged and well mixed with the rest of the population. Later, a second sample of the population is examined and 1% of the animals are found to be tagged. It may then be presumed that the population consists of 200,000 animals. There are several factors, however, that can make the method unreliable. It may be, for instance, that:

- the population is not closed; animals may enter the population between the two samples;
- the animals tagged are not a random sample of the population;
- the second sample (which will normally be part of the commercial catch) is not a random sample of the population;
- the presence of a tag may change the probability of the animal appearing in the second sample;
- tags may be lost from the animal before the time of the second sample; and
- some tags in the second sample may not be recognized or not reported.

These factors have been considered by scientists of the Department of Fisheries and Oceans, and the last three can be adequately dealt with (Bowen and Sergeant, 1983, 1984). It seems unlikely that the presence of a tag affects the behaviour of the animal, or its chances of being caught. Tags do wear off, but the rate of loss has been estimated by attaching two tags to the same animal. One method of analysing the results is to note the frequency of later returns from animals with only one tag, the other having become detached. Alternatively, the overall return rate from seals with two tags can be compared with that from seals originally tagged with only one tag. The return rate from seals with two tags will be greater because the loss of one tag will not prevent recovery , and the difference can also be used to estimate a rate of loss of tags. This estimate exceeds that obtained from observing the return of single tags from seals that were originally double-tagged. The reason for the discrepancy is not clear, but it will not make a big difference to the correction needed to allow for tag loss.

Few, if any, tags escape notice, but not all tags are returned. The frequency of non-return has been estimated by detailed inquiries among the sealing communities. Corrections for tag loss and non-return of tags can readily be made. The corrections actually made do not take into account double-tagged animals that lose both their tags in the same incident, or of non-returns that were not detected even in the follow-up. Thus corrections may be too small, and this error may lead to overestimates of population size, but the effect is probably very small.

The first three factors are more troublesome. The only period when it is practicable to mark large numbers of animals is in the breeding season, when large numbers of pups can be marked in the breeding patches. Even if efforts are made to spread the tags evenly, there will almost inevitably be some degree of clumping; in particular, there is likely to be a discrepancy between the numbers tagged in the Gulf and Front herds. Animals may be recaptured as whitecoats or beaters in the same year or as older animals in subsequent years. There will have been little mixing of animals in their first few months of life, and the rate of return will depend greatly on the degree of overlap of the positions of tagging and hunting. Whitecoat returns are of limited value for total population estimates, but they can be used to estimate production in individual patches if tagging can be well spread throughout the patch.

Beaters will be better mixed, and there seems to be good, but not complete, mixing within the Front or Gulf herds. Returns from the catches of beaters can therefore be used with caution to estimate the pup production in one herd or the other. Estimates for the total production can best be obtained by summing independent estimates for the two herds.

Better mixing will be obtained after at least a year, by looking at the occurrence of animals tagged as pups in 1978 among the catches of one-year-old animals in 1979, two-year-olds in 1980, and so on. This introduces the problem of knowing just how many one-year-old animals were caught in 1979, as well as various problems of adequate sampling and of possible errors in age determination.

Confidence limits on the estimates can be calculated to take account of some of the known sources of variation, particularly the relatively small numbers of animals tagged. These, typically, give coefficients of variation of some 10%–20%; that is to say, differences between pairs of estimates of less than about 30% cannot be considered statistically significant. These calculations cannot take account of all the sources of variation, especially when

the basic assumptions of the method are not entirely satisfied. These assumptions are likely to be particularly important when analysts are comparing results from tagging with those from surveys or other methods.

Sufficient pups have been tagged in eight years to give usable results. These results are summarized in Table 21.2. These figures are reasonably consistent; they will be compared later with those from other sources.

Table 21.2
Estimates of Pup Production (000s) from Mark-Recapture Experiments

Year of Tagging	From First Year Returns			From Later Returns
	Gulf	Front	Total	Total
1964	127–154[a]			
1966	120[b]	189[d]–200[b]	320[b]	
1968	120[b]–127[a]			
1970	68[a]–74[b]			
1977				318 (222–414)[c]
1978			2,245[c]	497 (429–565)[d]
1979			698[c]	478 (408–548)[d]
1980			309[c]	475 (381–565)[d]
1983			534[d]	136[d]

Note: The estimates distinguish between returns within a year of tagging and later returns. Confidence limits, when given, appear in parentheses.

Source:
a. Sergeant (1975, Table 50).
b. Sergeant (1975, Table 52).
c. Bowen and Sergeant (1983, Tables 13 and 16).
d. Bowen and Sergeant (1984). These differ very slightly from the figures in Bowen and Sergeant (1983, Table 16), by the inclusion of data from returns in 1982.

The very high figure from first-year returns in 1978 (and to a lesser extent in 1979) is probably the result of incomplete mixing and, as noted by Bowen and Sergeant (1983), is less reliable than other estimates. The low

estimate from later returns of animals tagged in 1983 is less easily explained. Bowen and Sergeant (1984) suggest that it may have occurred because most of the catch was taken close to shore, though there may also have been difficulties in estimating the number of one-year- old animals caught. In contrast, they suggest that the absence of a large whitecoat hunt in 1983 allowed a better spread of tags on the breeding patches so that the first-year returns might have been more reliable than those of previous years.

Survival Index

The principle of this method, first developed by Sergeant (1971), is straightforward. If unusually large numbers of pups are killed, fewer survivors will recruit to the stock of older animals, and there will be a relative scarcity of that year-class in the age composition of samples taken from the stock in later years. The relative abundance, or "survival index", of a year-class can thus be quantitatively related to the harvest of pups, to produce an estimate of the number born. This estimate will be the point on the line that relates survival index to pup kills at which the survival index falls to zero, that is, all the pups are harvested.

The practical application of the method faces two problems: births are not constant from year to year so that the number of survivors is not uniquely determined by the numbers harvested; and it is not easy to attain a "survival index" that is truly proportional to the numbers surviving. These problems have been examined in a number of published papers which have progressively refined the methods used (Sergeant, 1975; Benjaminsen and Øritsland, 1975; Ricker, 1975; Winters, 1978; Beddington and Williams, 1980; Roff and Bowen, 1983). The most recent study was recorded in a Ph.D. thesis presented in 1983 at the University of York, U.K. by J. Cooke; its main points are given in Cooke (1985), from which many of the present conclusions are derived. Although the later studies have detected and removed several weaknesses in the original form of the method, the changes in the estimates are not large, generally amounting to a few tens of thousands in estimates of some hundreds of thousands. These differences would be significant if management were concerned with determining the maximum possible allowable catch which would still permit some small increase in population. For other management objectives, the differences are not important.

There is little information on random year-to-year changes in pup production, as a result of environmental factors, for example, but the impression from the findings is that the proportion of adult females breeding

each year is high and does not change much. Such minor changes as do occur probably affect the estimates little, but a trend in population, such as the probable downward trend in the two decades leading up to the early 1970s, could cause a bias. Simulation studies suggest that the pup production will be overestimated, though probably not by much; that is, the estimate is equivalent to the population numbers near the beginning of the period under review, and not to the true average. It seems probable, though, that this conclusion only holds if there is a similar trend in the numbers of pups killed. In that case, high kills are associated with high initial numbers of seals, so that the effect of the harvest is underestimated, and the pup production is overestimated. If, on the other hand, there are opposite trends in harvest and pup production, then high kills will be associated with small numbers of seals and the impact will be overestimated and the estimate of production biased downwards.

The essential conclusions are that the "survival index" method should be used with care when there are trends in population numbers, and that it should be used only for relatively short periods (say, five to 10 years) during which population changes are likely to be relatively small.

The chief difficulty lies in obtaining a valid index of survival. Any sample from commercial or research catches will be selective according to the time and place of sampling, so that the proportion of a year-class in a sample will not be a true representation of the proportion of that year-class in the stock, that is, the survival rate. This problem can be dealt with by suitable processing of the sampling data, assuming that the density pattern of a given sampling method (such as that in the commercial catch at a given time and place) is the same from one year to the next, and that year classes suffer the same rates of natural mortality after the first few months of life. These are reasonable assumptions, except possibly for selections for one-year-old animals, which are variable.

For the older animals, in particular, uncertainties in age determination are another source of bias. Any errors will tend to reduce the apparent differences in survival rate and hence lead to underestimates of the impact of harvesting and overestimates of population abundance. Cooke (1985) has developed a method of correction that can be applied by using the known differences among determinations of the same animals by different observers as the only source of error. The correction given by this method must provide a minimum estimate of the error, since there will presumably be some, but an unknown number of occasions when two observers agree on an interpretation which differs from the true age of the animal. With this

qualification, Cooke's estimates based on samples of animals from two to eight years old, with a correction for the known extent of aging errors, are probably the best to be obtained from this approach.

Averaging the estimates given by the maximum likelihood and the least squares methods of statistical fitting gives, for the average annual pup production in 1958–1967, an estimate of 445,000 and an estimate of 324,000 for the period 1968–1977.

Sustainable Yield and Changes in Population Abundance

The estimates recorded in the preceding section mostly fall in the range of 200,000–600,000 pups born annually. Because they have been made by different methods and refer to different years, they are not immediately comparable. Before attempting a detailed comparison and an estimation of the changes in population abundance during the period, it is helpful to consider the factors that will cause the abundance to change. These factors are the births of young animals, the harvest by man, and deaths from natural causes. Given these factors, the changes in the population abundance can be determined by simple accounting. The natural mortality rate (M) among adult seals is not known directly, but can be inferred with reasonable precision from the observed age composition of the seal population. It must be fairly low to allow 20- to 25-year-old seals to be common, and it is probably close to 0.10 (i.e., 10% per year). A range of feasible values of 0.08–0.11 has been given by the working group of the International Council for the Exploration of the Sea (ICES, 1983). Except for some values that have later been shown to be based on erroneous methods, most other published values fall in this range. Since underestimation of the true mortality rate will have more serious consequences on the projections of future population trends, extreme values of 0.08–0.12 will be used here, although the true value more probably lies in the range of 0.09–0.11. It is likely that the mortality rate for young and very old seals (those over 25 years of age) is higher. A higher value for old animals makes little difference because the numbers in this age group are small.

A higher value would also be expected for younger animals; the difference in this age group would be expected to be greatest in the first few months of life, and it would decline until that for three- or four-year-olds becomes very close to the adult mortality rate. The only direct evidence on mortality rates comes from counts of dead, dying or sickly pups on the ice. These rates are low, suggesting that early mortality rates for harp seals are

much lower than those for some other seals, such as grey seals in the United Kingdom or fur seals in the Pribilofs. It may be that higher rates do occur when the harp seal pups first enter the water and have to feed themselves, but there is no evidence of significant occurrence of dying juveniles or of high predation. Most attempts to estimate mortality in the first few years of life have used cohort analysis or similar methods of extrapolating back from a known population of older animals which depend on an assumed value of natural mortality. Though these methods are of some use in tending to confirm that natural mortality is low, they are of little value in providing a direct estimate of M. For the purpose of calculating sustainable yields, upper limits of M that are three times that of the adult animals have been used for the first year of life, and corresponding limits that are 50% higher have been used for the rest of the juvenile stage. (See Appendix 21.1.)

The natural mortality rate is notoriously difficult to estimate in any natural population, but the long life of harp seals makes it relatively easy to estimate total mortality. Given estimates of total population, the fishing mortality (exploitation rate) can be estimated directly from the numbers of seals caught, and the natural mortality follows by subtraction.

Since the fishing mortality on adults is only a small part of the total (unlike the situation in many fish stocks), the resulting estimate is reasonably good, and can be further improved by additional analysis. The limits set out above are therefore generous.

Sustainable Yield and Replacement Yield

Given the natural mortality rates for harp seals at each stage of life, the average age at which females will produce young for the first time, the fertility rate and the sex ratio, it is possible to determine how many young a batch of, say, 100 pups would produce in their life, in the absence of any hunting. If this number exceeds 100, then the surplus can be taken, and will be equal to the sustainable yield. The details, which follow similar calculations in a number of reports, are set out in Appendix 21.1.

Alternative calculations are given in Appendix 21.1 for a range of feasible values for the different population parameters. The average age at first whelping can be reasonably well determined; the most recent (1978 and 1979) data set it at a little less than five years (Roff and Bowen, 1983, Table 3). Higher values of up to eight years have been observed in the past, and these are included. The fertility rate seems to be close to 0.94 at present, but

again, different (lower) figures have been observed in the past, and these are examined in Appendix 21.1. The changes in age at maturity and fertility are almost certainly related to the abundance or density of the stock and have important implications for the long-term dynamics of the stock. These will be considered in the section entitled "Future Management and Monitoring" (below).

From Table 21.8 in Appendix 21.1, it can be seen that the only combinations of conditions for which there is no sustainable yield (i.e., under which 100 pups will, in the absence of any hunting, produce fewer than 100 young during their lives) are those of high mortality, low fertility and high age at first whelping; these conditions do not apply at present. That is to say, under present conditions, in the absence of hunting, 100 pups would produce more than 100 young, and the stock would increase. The only report which is in apparent contradiction to this statement is that presented by the Nature Conservancy Council of the United Kingdom (NCC, 1982) for the Commission of the European Communities, and it states: "It cannot be said with certainty that the stock will recover, even if all hunting ceases." This statement was made in the context of changes in food supply, which would alter the carrying capacity for harp seals. Thus, while the stock will increase, it is by no means certain that it will recover in the sense of returning precisely to its pre-exploitation abundance.

By looking at Table 21.8, it can be seen that for the more likely values of the parameters ($M = 0.09$–0.11; age at first pregnancy of five to six years) the sustainable yield, taken as pups, is some 30%–60% of pup production. The value is particularly sensitive to differences in M and less sensitive to the total mortality between birth and first pregnancy. The effect of different pregnancy rates (given in Table 21.9, Appendix 21.1) is rather small.

Table 21.8 also shows that the sustainable yield, if harp seals are taken as pups, is about twice the sustainable yield if they are taken as adults. The difference increases with an increasing natural mortality rate and increasing age at first pregnancy. It is, as might be expected, about equivalent to the total mortality between birth and first pregnancy.

The sustainable yield is therefore not a single number, but depends on how the harvest is taken. This fact has been recognized by most recent assessments, which generally give a sustainable yield on the assumption that this figure is taken as consisting of 80% animals in their first year (i.e., pups or beaters) and 20% older animals. This formula, however, while cor-

rect as far as it goes, does not express explicitly the range of options open to the manager, and the extent to which taking the harvest as a larger or smaller proportion of old animals reduces the total number of seals that can be taken, compared with a harvest consisting wholly of pups. It seems preferable to express the sustainable yield as, say, the number of pups, or "pup equivalent", together with an indication of the number of pups equivalent to a given harvest of adults or older immatures.

The calculations of sustainable yield presented here are strictly correct only for an equilibrium situation, in which the population has reached equilibrium and the population parameters remain constant for some time. In practice, the population in any given year will differ in its structure from an equilibrium population to an extent depending on its recent history. Thus the population in 1971 had, because of the high pup harvest in the preceding years, fewer young animals than an equilibrium population of the same total numbers. There would therefore be relatively more births and fewer deaths. A harvest equal to the sustainable yield for an equilibrium population with the same total number of all animals would have allowed an increase in number. Conversely, at present, because of the regulations applied since 1971, there are relatively more young animals so that taking the sustainable yield for an equivalent equilibrium population would cause the stock to decrease.

For tactical year-to-year management, it may therefore be necessary to consider the *replacement yield*, that is, that yield which, if taken during a single year, will leave the numbers in the population at the end of the year the same as those at the beginning. Since there may well be changes in the composition of the stock, with the relative numbers in each age group coming closer to that of the equilibrium condition, the replacement yield at the end of the year may not be the same as that at the beginning of the year.

Recent Changes in Population Abundance

Some of the most controversial scientific arguments about the seal hunt concern the recent changes in abundance of harp seals. There are two independent approaches to this topic: to compare estimates of abundance at the beginning and at the end of the period concerned, or to compare the catches made during the period with the average sustainable yield, using estimated values of the population parameters. A mixed approach is also possible, using sets of the population parameters to simulate the changes in population numbers, taking into account the catches, and finding which set best matches the direct data (e.g., from tagging) on population abundance.

The first method is perhaps the most convincing, particularly when the same technique is used throughout the period. However, it is useful only when the changes are greater than the statistical variation in the estimates. Thus the survey data (Table 21.1) show fairly conclusively that the pup production decreased between 1950 (estimate of 645,000) and the 1970s (estimates of 225,000–250,000).

The problems in later years can be illustrated by reference to the data below, presented by the ICES working party (ICES, 1983) in its report.

Year	Method	Pup Population (000s)
Late 1960s	Modified survival index	320–420
1977–78	Tagging	380–500

On the face of it, these data suggest an increase. However, the two ranges overlap so that the population could have declined, for example, from 410,000 to 400,000. More serious is the fact that the methods are different and subject to different sources of bias. There are several reasons, including loss of tags and failure to return tags, why the tagging estimates could be biased upwards. Even if the degree of bias is small so that the estimates are still useful measures of the abundance, the biases could still be big enough to invalidate the estimates as evidence of a population increase during the 1970s. In brief, the various estimates, including those not mentioned in the tabulation above, are not good enough to demonstrate an increase, though they are more consistent with an increase than a decrease. A similar conclusion may be reached from the index of relative abundance provided by the catch-per-unit effort made in Greenland, which shows some increase since 1970 (Kapel, 1985).

After 1971, as a result of regulations, there was a sharp fall in the number of pups killed. In terms of pup equivalents, and taking one seal aged one year or older as equivalent to two pups, the harvest dropped from over 400,000 in most years up to 1967, to an average of 190,000 in 1972–1976 and 230,000 in 1977–1982, and to 106,000 and 77,000 in 1983 and 1984, respectively (Table 21.3). In the 1970s, the number of pups born was, to take a convenient round figure for the purposes of illustration, about 350,000. That is, the harvest was equivalent to taking about 54% and 66% of the pups in 1972–1976 and 1977–1982, respectively. Reference to Appen-

dix 21.1, Table 21.8 shows that both these rates are below the sustainable rate for several combinations of parameters, and the 54% rate, at least, would allow the population to increase for many of the more probable values.

Table 21.3
Catches and Quotas of Harp Seals in the Northwest Atlantic, 1970–1985

Year	Landsmen[a] Canada Quota	Landsmen[a] Canada Catch	Total Commercial[b] Canada and Norway Quota	Total Commercial[b] Canada and Norway Catch	West Greenland Catch	Total of All Catches	Pup Equivalent[c] (000s)
1970[d]	–	47,078	–	257,495	5,747	263,242	310
1971	45,000	47,197	245,000	230,966	5,001	235,967	262
1972	30,000	24,128	150,000	129,883	5,591	135,474	155
1973	30,000	45,382	150,000	123,832	8,700	132,532	166
1974	30,000	40,420	150,000	147,635	6,422	154,057	193
1975	30,000	53,539	150,000	174,363	5,000	179,363	220
1976	30,000	66,487	127,000	165,002	4,904	169,906	212
1977	63,000	60,191	160,000	155,143	6,257	161,400	199
1978	73,000	94,531	170,000	161,723	7,662	169,385	233
1979	73,000	63,166	170,000	160,541	12,774	173,315	217
1980	73,000	76,386	168,200	169,526	12,270	181,796	240
1981	70,800	107,572	168,200	197,832	13,605	211,437	256
1982	75,500	64,516	175,000	166,739	17,244	183,983	230
1983	75,500	47,339	175,000	57,889	18,739	176,628	106
1984	75,500	30,273	175,000	30,900	17,061	47,961	77
1985	75,500	17,723 [e]	175,000	17,723 [e]	–	–	–

Source: Quota and catch data
1970–1978: ICNAF (1972, 1973, 1974, 1975, 1976, 1977, 1978, 1979, 1985)
1979–1982: NAFO (1981, 1982, 1983, 1984)
1983–1984: Moulton (1986); Cooke et al. (1986, Appendix, Table D)
1985: Canda, DFO (undated, 1986).

a. Landsmen includes longliners, small vessels, and shore fishermen.
b. Total commercial includes landsmen and large vessels.
c. Calculated as: one animal age 1(+) = 2 pups, from data in Cooke et al. (1986, Appendix, Table A).
d. Quotas were not set for 1970.
e. Preliminary data for Newfoundland and Quebec only.

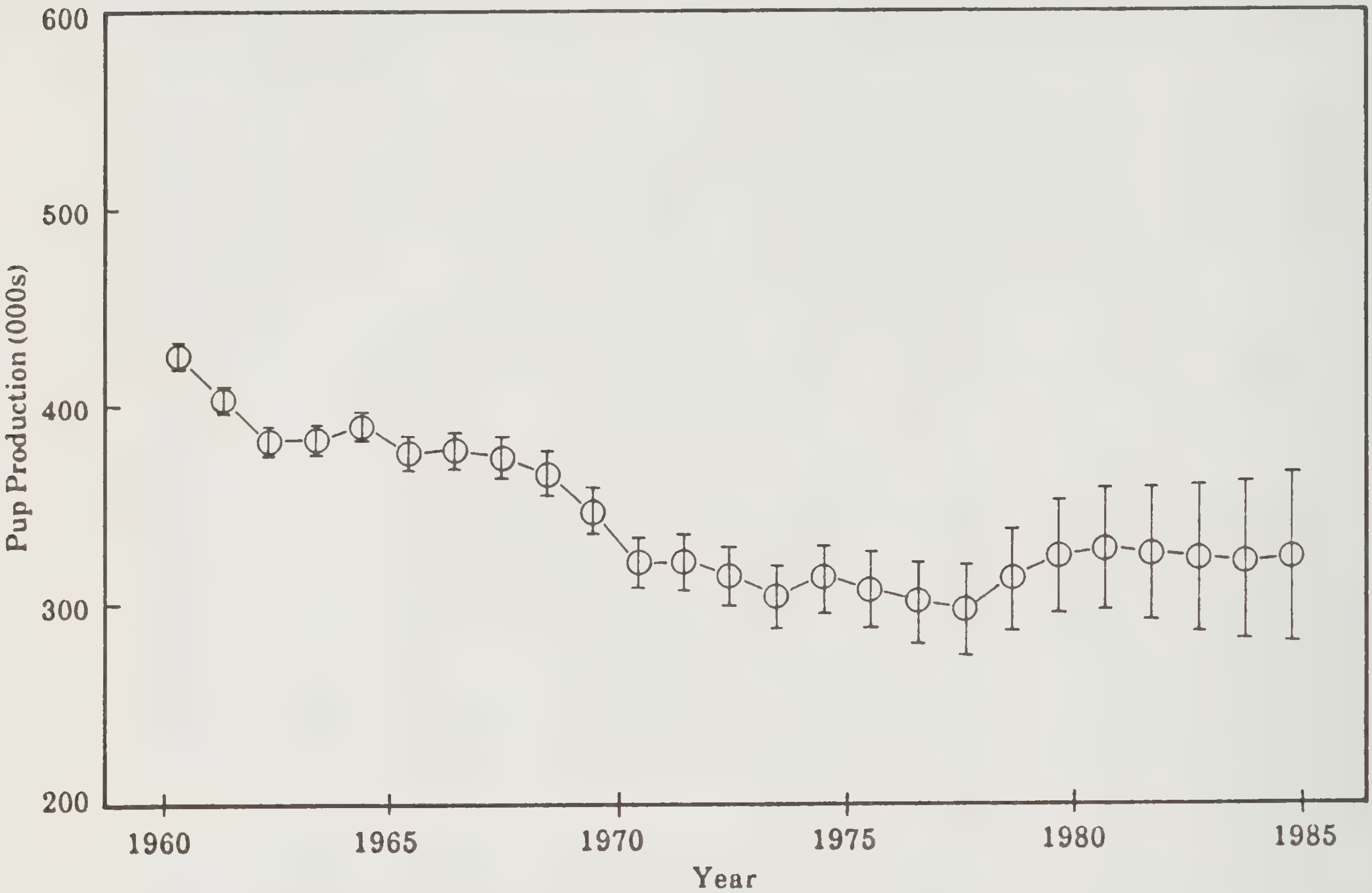
Too much should not be read into this analysis. Apart from the rough figure used for the pup production, the population was almost certainly not in equilibrium, so that the replacement yield was probably different from the sustainable yield. The ICES working group did calculate replacement yield and came to similar conclusions: that is, for three out of five sets of alternative parameter values, the replacement yield was greater than recent catches. For the other two sets, in the worst case the catches were 22,000 in excess of the replacement yield, which is to say that the population would have decreased by 22,000 in that year. It should be noted that the ICES calculation used an 80:20 ratio in the harvest of pups and older animals. In all recent years, except 1981, the proportion of older animals has been higher, which would slightly reduce the replacement yield.

A convenient way of examining how numbers of seals changed in recent years is by sequential analysis or simulations of the year-to-year changes in numbers under various combinations of population parameters. The most up-to-date simulation of the recent history of the harp seal has been carried out at the University of British Columbia (UBC) under contract to the Royal Commission (Cooke et al., 1986). A typical result of this simulation, using age samples of seals taken from nets during the period 1961–1984, is given in Figure 21.3.

The other fixed inputs to the simulation were the pregnancy data, but the mortality rates and age selectivity of the gear (which are confounded together and cannot be estimated separately) and the initial pup production were adjusted to fit the observed age data. This method of fitting, which essentially matches disturbances in the age data to the catches, is roughly similar to the survival-index method. Different results were obtained with different sets of age data. These simulation results, giving the estimated pup production in 1978, are given in Table 21.4, which also includes some reanalysis of the tagging data carried out by the UBC study (Cooke et al., 1986).

The first conclusion about this table is that there is a reasonable degree of consistency, especially considering that the figures are derived from three entirely different methods with independent sets of data and different sets of assumptions. The data sets, but not the assumptions, are also independent for three estimates from tagging. This range of methods and the degree of agreement between them are unusual in the study of wild animals and give considerable assurance of the reliability of the results.

Figure 21.3
Estimates of Annual Pup Production (I)[a]



Source: Cooke et al. (1986).

a. From age samples of seals aged 3–11 taken in nets, 1961–1984. Vertical bars indicate standard errors.

The second conclusion is that there are consistent differences between methods, with the tag-recapture estimates higher and the census estimates lower than those derived from the age samples. These differences might be the result of a sampling error, especially for the single estimate from the aerial census, but they are in the directions that might be expected from the possible sources of bias that can occur in the methods: missing part of the breeding area in the census and incomplete returns or loss of tags. It also proved impossible in the simulation studies to find simulations that were consistent with the age data, and for which the confidence limits straddled the results obtained from tagging. The Royal Commission therefore accepts that there is some degree of positive bias in the tagging data, and possibly some negative bias in the survey data. The Royal Commission's best estimate is therefore that the pup production in 1978 was 300,000–350,000.

These figures can be used to provide estimates of the number of mature females from the pregnancy rates, and the total numbers of animals aged one year or older (the 1+ population) from mortality and maturity rates and the sex ratio. Different values of these rates will give slightly different ratios of pups to 1+ animals, though the range is not great. Roff and Bowen (1983) and ICES (1983) used a ratio of 1:4. Use of this ratio gives a 1+ population in 1978 of 1.2–1.4 million, or a total population soon after the pupping season of 1.5–1.75 million.

Table 21.4
Estimates of Recent Pup Production (000s)[a]

Year	Method	Source Data			Pup Production
1978	Age samples	Large vessels	1961–84	Age 3–11	358 (34)
1978	Age samples	Nets	1961–84	Age 3–11	295 (24)
1978	Age samples	Others	1961–84	Age 3–11	341 (92)
1978	Age samples	Large vessels	1961–84	Age 3–6	296 (27)
1978	Age samples	Large vessels	1973–84	Age 3–11	331 (45)
1978	Tag recoveries	Long-term returns	1979–84		536
1979	Tag recoveries	Long-term returns	1980–84		532
1980	Tag recoveries	Long-term returns	1981–84		482
1977	Aerial census	(1977 Front + 1975 Gulf)			251 (110)

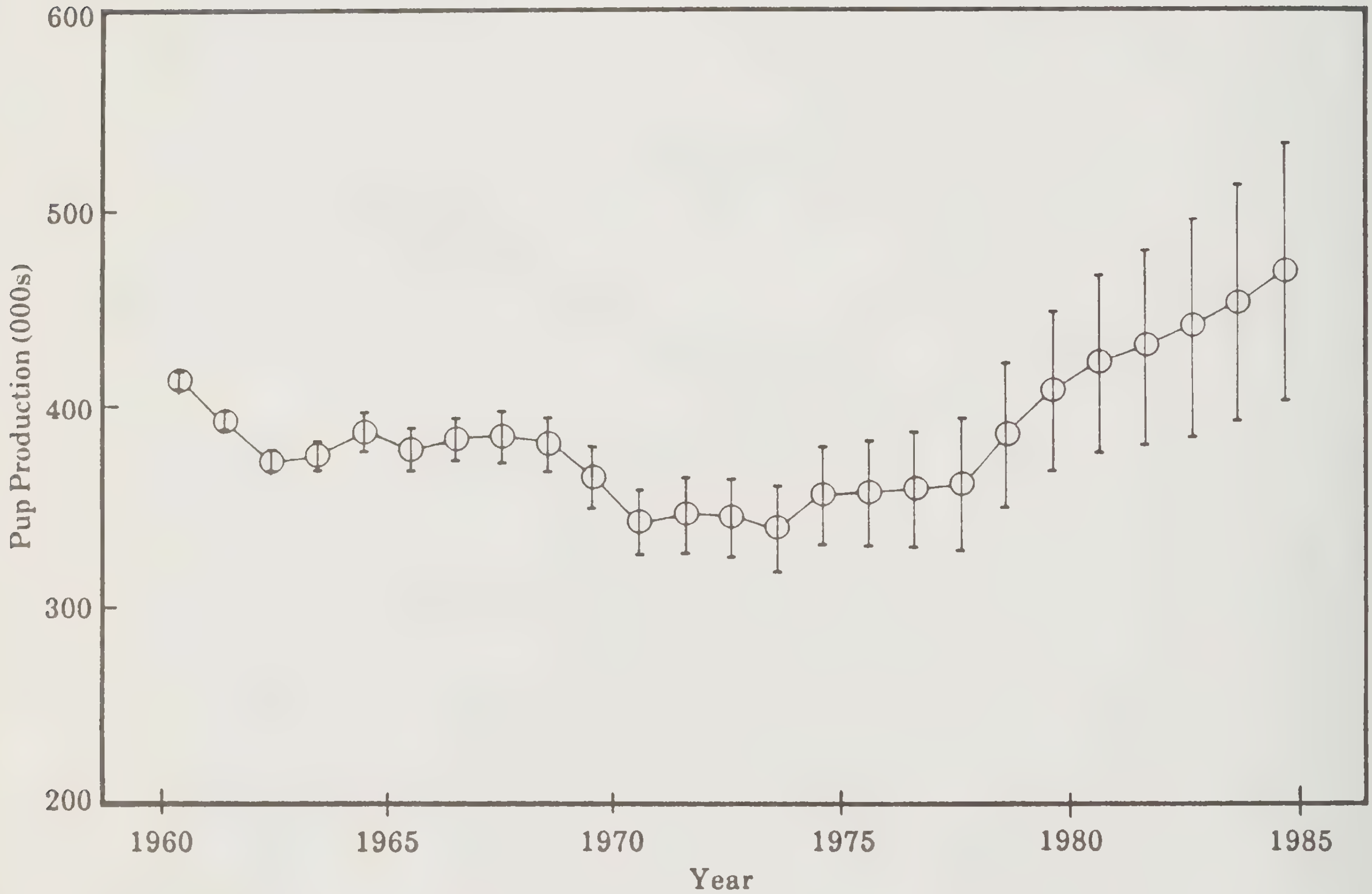
Note: The figures for tag recoveries differ slightly from those in Table 21.2 because of new analysis of the data.

a. Confidence limits (±) are given in parentheses.

The simulation models allow some insight into the likely changes in population abundance over the last 20 years, the period for which some estimates are available. A comparison of Figures 21.3 and 21.4 shows that there are differences in the pictures presented by different data sets, especially for the most recent years. The changes apparent during the period covered by most estimates (such as those presented by ICES, 1983), that is, from the late 1960s to 1980, are likely to have been complex, with an initial

decline, a halting of the decline, and then, possibly, a recovery. Such a pattern is unlikely to be detectable by examining a set of population estimates for a few individual years.

Figure 21.4
Estimates of Annual Pup Production (II)[a]



Source: Cooke et al. (1986).

a. From age samples of seals aged 3–11 taken by large vessels, 1961–1984. Vertical bars indicate standard errors.

If trends in population abundance are to be used to judge the effectiveness of management measures, the first year-class to have been significantly affected by the quota measure was that of 1972, most of which would not breed until 1977. It would not be until the early 1980s that more than a small proportion of the breeding stock would be made up of seals that might have benefited from the quota limits on pup kill.

Assessment of recent trends has to be made, therefore, largely from a comparison of catches with estimates of sustainable yields, increasingly so as

the most recent years are approached. On this basis, taking account of the range of likely values of the parameters and the direct estimates of population abundance, the conclusion that fits the data best, and that is based on the central values of the parameters, is that the total population has increased from 1972 onwards, with the changes in pup production being delayed some four or five years. However, neither no change nor a decrease can be ruled out. If there has been a decrease, then the catches will have exceeded the replacement yield by a small amount, and the decrease will have been slow. In 1983, the catches were below any reasonable value of the replacement yield, and the stock presumably increased. The 1983 population was probably slightly above the 1978 population, amounting, that is, to slightly more than 1.50–1.75 million. The Royal Commission's estimate of the present population at the end of 1985 is, therefore, in round numbers, some two million.

Management Measures

Prior to the 1950s, management of the seal harvest, in the sense of controlling the numbers and types of seals killed in order to maintain a healthy stock, had not been very widely considered. During the 1950s, scientific studies, such as Fisher (1955), began to give warnings of the effect on the stocks of uncontrolled harvesting, and the first quantitative studies of the numbers of seals and the sustainable yield were made (Fisher, 1955; Sergeant, 1959).

At that time, the Front area was largely outside Canadian jurisdiction and international agreement was necessary for effective management there. In 1961, Canada proposed that seals and sealing should be brought within the responsibility of the International Commission for the Northwest Atlantic Fisheries (ICNAF). This suggestion was agreed to, but it was not until 1966 that the last ICNAF member country, Italy, finally ratified the agreement, and ICNAF could consider seals.

Meanwhile, in October 1964, the Canadian government set a quota of 50,000 pups for the large vessels operating in the Gulf area (inside national jurisdiction). The main management measures, however, were concerned with operational aspects aimed at reducing waste and cruelty. These included specifications for the clubs that could be used, protection of adults on the breeding patches, and a requirement to remove pelts from the ice within 24 hours.

When ICNAF did gain responsibility for seals, there was some considerable discussion over the scientific evidence, including arguments over the degree of mixing between the animals breeding in the Gulf and Front areas. It was not until 1970 that ICNAF agreed on quotas, setting the quota for 1971 at 245,000 animals, including an allowance of 45,000 for landsmen. At that time it was agreed that catches by aboriginal peoples in Greenland and northern Canada would be outside the quota system. It was recognized, as well, that catches by Canadian landsmen varied with ice conditions and could not easily be controlled. The quota therefore included an allowance for landsmen, with the expectation that the overall quota would be exceeded in some years (as it was in 1975, 1976 and 1981), but that over a period the average catches would be within the quota. The subsequent history of quotas and actual catches are given in Table 21.3.

In 1971, the Canadian government set up the Committee on Seals and Sealing (COSS). Both COSS and the scientists in ICNAF expressed considerable concern about the state of the stocks, and some studies indicated that the adult stock would decline for some years even if no more pups were harvested. COSS (1971) recommended a phasing-out of commercial sealing, starting with a quota of 150,000 (large vessels plus landsmen) for 1972, and 110,000 for 1973, 70,000 for 1974 and zero in subsequent years. Within ICNAF, the scientific advisers recommended a quota of 150,000, which was put into force. During the next few years no major new assessments of these stocks were undertaken, and the quota was kept at the same level.

In September 1975, a special meeting of scientists was held to review the information, including the first results of aerial surveys using ultraviolet light. There was agreement that the state of the stock was poor, showing a reduction in breeding stock believed to amount to about 12.5% per year, and that a moratorium on harvesting was desirable. Some scientists from other countries did not accept these results. Despite two meetings of the ICNAF scientific advisers, held in November and December 1975, it was not possible for participants to agree on a single quota, and quota recommendations ranged from 90,000 to 127,000 animals. ICNAF then implemented the higher figure.

After 1975, the balance of scientific advice became less pessimistic. There was general agreement that the stocks were below the level of the maximum sustainable yield (MSY) – which was commonly accepted as at least a reference level for guidance, if not necessarily as the definitive target – and that the stocks should be increased, but there was less concern over the possibility of a further, and possibly catastrophic decline. The ICNAF scien-

tific advisers, meeting in October 1976, received reports that mostly indicated that the sustainable yield was in the range of 199,000–215,000 and recommended a total allowable catch (TAC) of 170,000. Against this, one analysis (Capstick et al., 1976) estimated a sustainable yield of about 103,000–130,000. ICNAF adopted a TAC of 170,000, including 10,000 for Greenland and Canadian aboriginals, leaving 160,000 harp seals for the commercial hunt.

In subsequent years the picture was much the same. No complete agreement was reached on the scientific analysis, and doubts were expressed on matters such as new methods of analysis introduced by Beddington and Williams (1980) or the precise value of the natural mortality rate.

Some scientists continued to be concerned about the state of the stock, and this concern was expressed in reports such as that prepared by the Nature Conservancy Council (NCC, 1982), of which the summary states that "There is a *risk* that the population would be *endangered* by a continuation of present rates of exploitation" (emphasis in original), though there seems to be no basis for this statement in the main text of the report. The summary states earlier that "It is uncertain whether this stock – for which the range of current estimates is 1–2 million animals – is increasing or decreasing, although any change in size can only be small." This is hardly a conclusion that implies significant risk. In the light of this uncertainty, the formal advice to ICNAF and by its successor after 1979, the Northwest Atlantic Fisheries Organization (NAFO), was to continue the TAC at the same level, except that the allowance for the aboriginal catch was in addition to, rather than part of, the 170,000 TAC.

Examination of Table 21.3 shows that the quota management did achieve its immediate objectives. Catches from 1972 onwards were sharply reduced from the 1970 level, which was fairly typical of the preceding years. Though the landsmen's catch often exceeded the planned figure, the total commercial catch only exceeded the TAC in four years: 1975, 1976, 1981 and a slight excess in 1980. Overall, the total catch from 1971 to 1982 (the last year before the market collapse affected the catches) was less than the sum of the TACs. The TACs set were also in accord with the formal scientific recommendations, though it must be recognized that these were often reached only after long discussions and were sometimes the figure that could be most widely accepted, rather than the best figure in any scientific sense or the most cautious figure.

Did the quota management achieve its long-term objective and move the stock towards its most desirable level? This is the more important ques-

tion, but it is difficult to answer even if it were clear what was the most desirable stock level. Though achieving MSY had considerable support as the principal objective, it was not fully adopted, and the most commonly expressed objective was to increase the stock or, as it was sometimes expressed in later years, to allow the stock to continue to increase. Whether it did or not has been examined in the previous section, and the answer reached was probably, but not certainly. What can now be said with certainty is that after 1972, the stock did not decrease greatly, and the most pessimistic scientific views expressed in the mid-1970s – for example, that the stock was decreasing at 12.5% per year – were indeed too pessimistic.

Long-Term Effects and the Maximum Sustainable Yield

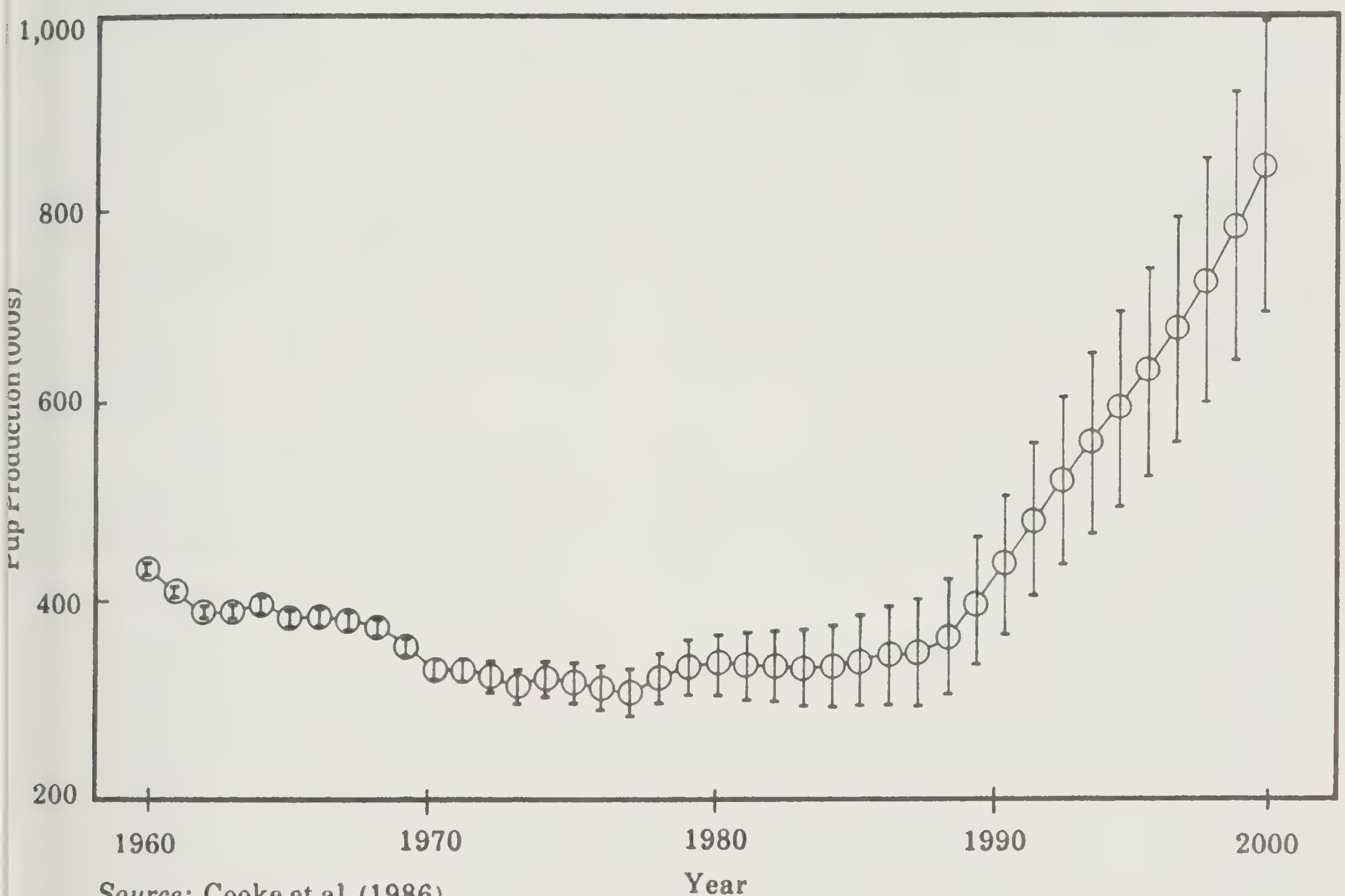
Density Dependence

From the preceding sections it is clear that in the absence of any hunting, the present harp seal population would tend to increase. The exact rate of increase is not known; it might amount to only a few percent, or it might be similar to the 13% increase annually observed for the grey seal on Sable Island. If it were only 4% per year, and if this increase were to continue indefinitely, the pup production would double in 18 years and increase 10-fold in 60 years. (See Figure 21.5.) A 10-fold increase is most unlikely. There will be changes in one or more of the population parameters related to population density, so that the population expansion slows down and stops before the north Atlantic is covered with harp seals.

Some kind of density-dependent mechanism is believed to occur in all natural populations, but the actual density-dependent mechanisms are likely to differ from population to population. Unless there are good data for a long series of years during which the population abundance has changed significantly, it is difficult to know exactly what the mechanisms are in a particular case. The harp seal provides no exception. There is reasonable evidence, however, that as the population increases, the animals mature later, and some evidence exists that the fertility rate decreases (Lett et al., 1979; Bowen et al., 1981; Bowen and Sergeant, 1981).

The quantitative interpretation of these and other data on density dependence is not straightforward. An apparently extremely useful method of observing changes in the ages at maturity of marine mammals, based on the interpretation of the same structures (ear plugs, teeth) used to determine

Figure 21.5
Example of Forward Projection of Pup Production[a]



Source: Cooke et al. (1986).

a. From estimates based on age samples assuming that no pups or seals aged 1 + are caught. Age samples from seals aged 3–11 taken in nets, 1961–1984. Vertical bars indicate standard errors.

age, has been shown to have a built-in methodological bias, and this finding has greatly changed some of the perceived ideas about the extent of this density-dependent process in marine mammals (Cooke and de la Mare, 1983). Procedurally, the least problems derive from direct observations of samples of animals to determine their age and whether they are mature. Data from such samples are presented in Table 21.5, recalculated from Bowen et al. (1981). There are big differences between the January–February samples and the March–April ones. The mean age in the latter is often more than a year less than in the January–February samples. A year is the maximum difference that might be expected if most seals reaching maturity became detectable as doing so between the January–February and the March–April samples. The big differences suggest problems in these data, such as the difficulty of sampling mature and immature animals of the same age with equal probability.

Table 21.5
Estimates of Mean Age at Maturity of Female Harp Seals

Year	Jan.–Feb. Samples		Mar.–Apr. Samples	
1951–54	6.06	(0.48)[a]	–	–
1952–54	–	–	6.05	(0.18)
1961–62	–	–	4.89	(0.27)
1964	6.03	(0.29)	–	–
1965	6.67	(0.15)	–	–
1966	7.18	(0.40)	5.51	(0.22)
1967	6.77	(0.22)	–	–
1968	6.16	(0.20)	–	–
1968–70	–	–	4.56	(0.19)
1969	7.07	(0.26)	–	–
1970	7.14	(0.41)	–	–
1976	–	–	5.30	(0.37)
1978	5.90	(0.22)	–	–
1979	5.10	(0.17)	4.58	(0.17)
1980	5.56	(0.12)	–	–
1981	6.15	(0.32)	4.65	(0.16)

Source: Recalculated from Bowen et al. (1981).

a. Standard errors are in parentheses.

The January–February samples suggest a decrease in the age at maturity between 1965–1970 and 1978–1981, consistent with the drop in population numbers. It is difficult to relate this decrease precisely to density since the age at maturity (e.g., in the 1980 samples) is presumably related to the conditions for the young seals in preceding years (i.e., to the density in 1978 rather than in 1980), so that it is not clear which year's density should be related to which year's maturity data. Also, there are doubts about the exact values of the density in each year and about how the density has changed from year to year. Other factors, such as changes in food supply other than any created by changes in the seal population, could be having as much effect as seal density. In terms of the expected density-dependent re-

sponse, the early (pre-1965) January–February samples (but not the March–April 1952–1954 sample) are anomalous, but about that time there were environmental changes at west Greenland that were affecting other animals at least. The last good year-class of cod off west Greenland was that of 1963 (Cushing, 1982).

These data are far from conclusive. They are, however, entirely consistent with what one would expect of seals behaving according to ecological theory. Other things being equal, there was a considerable reduction in age at maturity as density fell, but there were difficulties in estimating the mean age at maturity, and this age was also affected by environmental factors.

It is also possible that the natural mortality changes over all or part of the life-cycle in response to changes in density. Apart from observations of dead or dying pups on the ice, however, there is no direct evidence related to natural mortality. The indirect evidence available, such as that taken from age-composition data, is sufficient to give a reasonable estimate of natural mortality as an average over the last few decades, but it is of little help in determining whether or not natural mortality among the older seals has changed. It can, however, be said with fair confidence that there is no observed occurrence in harp seals of high pup mortalities associated with high densities, similar to those occurring in northern fur seals and in grey seals in the United Kingdom, though Lett et al. (1979) present evidence of a substantial decrease of natural mortality of harp seals in the first year of life between the 1950s and the 1970s. There are reports of increased occurrence of wounded seals and seals in poor condition at high densities, but it is not possible to relate this in a quantitative manner to increases in natural mortality.

Examination of the tables in Appendix 21.1 shows that there are a number of combinations of changes in the parameters which would bring the population into equilibrium and which would be quite reasonable in the light of changes actually observed. Table 21.8 shows that a mean age of first whelping of seven, a natural mortality of 0.11 and a fertility rate of 0.94 would result in a sustainable yield of pups of only 17%, while no sustainable yield is possible with $M = 0.12$. That is, with an M between 0.11 and 0.12, the population would be in equilibrium in the absence of any killing. If the density-dependent relations for all the parameters were exactly known, it might be possible to calculate the population figure at which the net rate of increase would fall to zero, that is, the long-term equilibrium population. The information available is not sufficient to make this calculation possible with any degree of precision, but studies (such as that made by Lett et al.,

1979) give unexploited equilibrium populations in the range of 4–10 million animals, which are consistent with independent estimates of the size of the population when exploitation began, based on information on the numbers killed in the 19th and early 20th centuries.

Food and Environment

The current abundance of the harp seal population is not the only factor that can affect the population parameters. It is reasonable to expect (but unproven) that density-dependence acts, to some extent, through the association of a high density of seals with a reduced per capita food supply. The populations of the different species that harp seals feed on have not remained constant, since they are affected by environmental changes and, in some species, by human exploitation.

The effect of exploitation has been a general decrease in the abundance of fish stocks, and until the extension of the limits and jurisdiction in 1977, the management measures were not effective in reversing this decrease. Since 1977, most of the stocks have come under full Canadian control, management on the whole has been more effective, and some stocks are being rebuilt. This success has been variable, however, and many fish stocks are still at a relatively low level. The effect of these low levels on the seal stocks might be negative, though any effect is not easily detected. (See Chapter 23.)

One example of a negative effect has been suggested by Stewart and Lavigne (1984), who noticed a reduction in the condition of seals, as indicated by the thickness of the blubber of breeding seals between 1976 and 1978. This reduction occurred just after there had been very large catches of capelin from the stocks to the east and north of Newfoundland, and many believed that it was a simple case of cause and effect, showing how human overexploitation of a fish stock can affect seals. Later studies (e.g., Carscadden et al., 1984) have shown that though several capelin stocks did decrease greatly between 1975–1976 and 1978–1980, part of that decrease is probably the result of changes in year-class strength (Leggett et al., 1984) rather than of heavy fishing. Since 1980, the abundance of capelin in the northeast Newfoundland-Labrador stock has increased. It is not known how blubber thickness has changed in later years, nor what is the long-term effect of changes in condition on population parameters and on the dynamics of the harp seal population. In the short run, there seems to have been little effect. The age of first whelping in 1978–1979 was as low as in other recent years.

The absence of a demonstrable effect on population parameters would not be surprising. Though capelin are among the chief items in the harp seals' diet, the seals have a wide range of prey, and the partial loss of one item could be, to a large extent, balanced by increased attention to other items. Nevertheless, such a loss must have some cost, and the equilibrium population or the carrying capacity of the harp seals' environment cannot be considered as entirely fixed. In particular, to the extent that some of the harp seals' food (capelin, shrimp) is being increasingly exploited by man, it must be expected that one indirect effect of this increasing general level of exploitation of north Atlantic fisheries will be a reduction in the carrying capacity for harp seals and in the equilibrium population. However, because of the complex interactions between fish species, exploited or not, eaten by harp seals or not, these effects are not certain.

Two aspects of the possible effects on seal stocks of heavy exploitation of fish stocks or of environmental change need to be considered. In the first instance, if the effects are not very great, they will cause some change in population parameters, carrying capacity, and the values of sustainable yield and of the population level at which MSY occurs. Thus, heavy fishing of capelin could reduce the MSY population level, so that a population below the MSY level under the original conditions (and therefore under some criteria deserving of protection) might be above the MSY level corresponding to the new conditions (and therefore, under the same criteria, potentially exploitable). On the contrary, the sustainable yield (as a percentage of the population) under the new and less favourable conditions would presumably be lower so that quotas or other regulations would need to be adjusted to match the new conditions.

The more serious effect would be a reduction of the seals' food supply to such an extent that their existence was threatened; this would occur if the effective reproduction rate fell below the natural mortality rate. Such an eventuality would require very great changes in one or more of their parameters. Though this is a prospect that should be kept under review, it does not seem to be a serious possibility at the present time.

Many fish stocks were, in fact, seriously depleted in the 1960s and 1970s, when foreign fishery vessels had open access to the areas beyond the territorial waters of Canada. With the imposition of the 200-mile exclusive economic zone (EEZ), these waters are no longer open to foreign fisheries, and the aim of Canadian policy is to rebuild the fish stocks. Though this rebuilding will take time, the expectation is that the availability of fish will tend to increase in the future.

Consideration should also be given to possible changes in the predators on harp seals. These include polar bears, killer whales and Greenland sharks. The predation rate is stated to be low (Lavigne, 1979), but the evidence for this statement is poor and, even if the predation rate amounted to only a few percent per year, it would represent a significant part of the natural mortality rate. Although direct evidence is poor, Greenland sharks have probably been reduced by incidental catches in bottom trawls. The impact of exploitation on these predator species would act in the opposite direction to the impact on harp seals of exploitation of capelin and other food species.

Fishing has, too, a more direct impact on seals, when these animals die as a result of being caught or entangled in fishing nets. This problem is discussed in Chapters 23 and 25. It appears that in the past such entanglements have not been significant for harp seals, and it does not seem necessary to make allowance for accidental seal catches in the analysis of past population trends. Although there have been recent reports of an increasing number of seals becoming entangled in gill nets (e.g., Lien, 1985), it does not seem that the numbers of animals involved are sufficiently large to be significant in terms of total population, but the situation should be monitored. In any case, the number of seals killed incidentally should be taken into account when authorities are setting quotas on the basis of assessments of population status and sustainable yields.

Maximum Sustainable Yield (MSY)

In Appendix 21.1, calculations are made of the sustainable yield expressed as a proportion of the total numbers or the numbers of pups. The sustainable yield will depend on the values of the population parameters. As the population abundance changes, these parameters will also change, as will the sustainable yield expressed as a proportion of the population. Multiplying the proportion of seals that can be harvested by the actual production rate gives sustainable yield in actual numbers. This yield will be small both for a small population and for a large population that is close to the environment's carrying capacity. At some intermediate population level, the sustainable yield will be at a maximum. This maximum and the population level at which it occurs will probably be slightly different depending on whether the quantity maximized is expressed as number of pups or adults or immatures, or as some combinations of these groups. As the pup equivalent of an adult, given in Appendix 21.1, does not change very much, the difference in the position of MSY will probably be minimal.

When the greatest possible sustained harvest of seals is the prime management objective, the manager will probably try to maintain the population close to the level which gives the MSY, and thus an accurate knowledge of this level is of considerable concern. As explained in more detail in Chapter 27, this objective is not likely to be valid for harp seals. The manager is much more concerned with balancing the interests of those harvesting seals against both the interests of fishermen, who want a low population, and the interests of environmental or other groups, who want a very high population; these latter aims both imply populations with sustained yields well below MSY.

The significance of the MSY as a management objective is discussed in Chapter 27. There it is pointed out that although MSY has played an important role in the theory and practice of resource management, it does not have particular significance in the Canadian context. Those hunting seals, whether in Newfoundland or in the Arctic, need enough seals to satisfy their immediate needs – to bridge the gap in income before the fishing season or to feed their families – and above a certain level, increasing the volume of the catch is not a priority. Fishermen, who complain about the competition with seals or damage to nets, would rather see a low seal population. The seal population that corresponded best to the balance of interests between these groups and those with general interest in a healthy and balanced ecosystem could well be at a lower level than the MSY level, though still providing a reasonably large sustainable yield.

From the purely Canadian viewpoint, it is therefore not particularly important to know the precise level of population corresponding to MSY, or whether the population is above or below that level. However, there are other viewpoints. Under the United States *Marine Mammal Protection Act of 1972* there is a requirement to bring any population of marine mammals to the optimum sustainable population (OSP) level, which is effectively the MSY level and above. A knowledge of whether or not the harp seal population was at OSP, that is, at or above MSY, might be important in relation to the possible export of seal products into the United States.

This knowledge is difficult to obtain with any certainty. The empirical approach of observing the sustainable yield at different population levels is clearly impracticable. The standard approach is to compare the current population, as a percentage of the initial population, with the percentage at which the MSY occurs. The latter percentage depends on the form of density-dependent relationship. Since the fact of a density-dependent effect on the fertility rate, or age at maturity, is not easy to demonstrate conclusively with the available data, it is much more difficult to be confident concerning

knowledge of whether the effect occurs fairly uniformly over the full range of stock abundance (which would give an MSY somewhere around 50%), or mostly at high densities, closer to the maximum population. This would give a high MSY population level (60%–70% or more of the maximum population).

Some analyses, such as Figure 10 of Lett et al. (1979), even suggest density-dependent processes that give an MSY below 50%. For the present, though, there is no evidence that validates rejecting the accepted wisdom that the MSY for marine mammals, and for harp seals in particular, occurs well above 50% of the maximum population.

Equally, there are problems in determining the maximum population. Attempts to project the present population forward, which give estimates that range from four million to ten million (Lett and Benjaminsen, 1977; Lett et al., 1979) depend on making assumptions on how the density-dependent factors operate in order to reach the equilibrium point. Too little is known about the early history of sealing – doubts surround even the crude catch statistics – and the present data base is too remote from the beginning of large-scale sealing to make anything more certain than intelligent guesses about the original populations. Considering the very large catches that were taken in the 19th century, the larger, rather than the smaller, figures in the above ranges seem more likely.

For these reasons, it is not worth attempting to make a precise estimate of MSY and the population level at which it occurs. Lett et al. (1979, Figures 9 and 10) suggest that the MSY might be about 200,000–250,000 animals (taken in the ratio of 80:20 of pups to older animals), and that it might occur at population sizes of 1.5–3.0 million animals. The proportionately much larger range of population sizes than yields indicates the flatness of the sustainable yield curve near the maximum and the difficulty of precisely estimating the population level corresponding to MSY.

The population levels for MSY are somewhat above the likely values for the present population, but the difference is not large. Slightly different values for the present population or for the nature of the density-dependent processes or for the reduction in the carrying capacity (e.g., by exploitation of the fish stocks on which harp seals feed), could bring the estimate of MSY level below the present population figure.

Critical Population Size

The lower limits of population size, at which there is risk of extinction, are of major interest. At extremely low levels, when there are only a

few individuals, stochastic processes (i.e., pure chance) may result in the population becoming extinct even when, on the average, it would be expected to increase. At a slightly higher level of population, rather similar statistical considerations apply to the genetic composition. The population may contain so little genetic variability that it may not be able to accommodate small changes in conditions. Both of these considerations apply only to populations of the order of a few tens or hundreds. They are not causes for concern with respect to harp seals now, nor would they be even if the population was reduced to a figure well below the present level.

Of much greater potential concern is the possibility that the favourable changes in population parameters, which have occurred since the population has decreased from its original level, may be reversed at low population levels. Natural mortality or the age at maturity may increase, or fertility may decrease. There are no direct observations to indicate that any of these changes may happen, and there are theoretical reasons to believe that they are unlikely. The most probable cause of an increased natural mortality rate at low population levels would relate to a predator for which harp seals are a preferred prey. A given number of predators could take a fixed number of seals, which would imply an increased predation rate as seals decline. No such predator, other than man (in some circumstances), appears to exist. The observed decrease in maturation age at lower population levels is presumed to be associated with an increased per capita food supply, and there is no reason to suppose that this mechanism would cease to operate, or indeed reverse, at very low population levels.

Biological mechanisms that could result in reduced fertility can be imagined. In the extreme, the few surviving males and females might have difficulty in finding one another. This possibility is unlikely in a species that breeds in a few large concentrations, but it is possible to imagine requirements of social behaviour, such as the need for a high density of animals of the same species, as being important to the maintenance of fertility. There is no evidence that such circumstances apply to harp seals, but the possibility might be something to bear in mind if the harp seal population declines greatly below its present level.

A critical stock size of 800,000 animals has been mentioned by Lett et al. (1979); this figure is based on the observation that, according to the authors' estimates, below this number the population parameters no longer change in a favourable direction. Leaving aside the question of whether the observation is correct – and there certainly must be limits beyond which the fertility cannot increase, nor the age at maturity decrease – it is questionable to what extent this population size is in any sense critical. If for any reason,

including heavy fishing, the population is driven below this level, there will still be an excess of births over natural causes of deaths and, in the absence of exploitation, as strong a tendency to increase as in stocks just above this level. This population level is only critical in the sense that there is no additional resilience so that if some additional stress is imposed on a population that is already being heavily exploited, thus bringing it below the critical level, it cannot respond positively to the additional stress, and exploitation will have to be reduced to avert extinction. This really means that such populations need to be monitored particularly carefully.

Future Management and Monitoring

The preceding analyses show fairly conclusively that there are large numbers of harp seals (approaching two million), and that catches in the last few "normal" years were probably allowing the stock to increase. They also show that there are considerable doubts about many of the details pertaining to the dynamics of the seal populations. Therefore, there is a chance that if the 1980 policies and quotas were to be retained indefinitely, they would result in the depletion, and ultimately in the extinction, of the stock. This effect has been illustrated more conclusively by the simulation studies carried out by the UBC group under its contract with the Royal Commission (Cooke et al., 1986).

These studies show that when account is taken of uncertainties in the estimation procedures and of natural variations, there is a definite possibility that any management program, except for the most conservative, would drive the stock to extinction if it were continued over a long period without reference to what was actually happening to the stock. This situation is, to various degrees, common to many resources. It has resulted in several environmental groups calling for the implementation of very conservative policies until the doubts are removed. This, for example, is the principal reason for the International Whaling Commission (IWC) moratorium on all commercial whaling. A plea for a similar moratorium on the commercial hunt for seal pups was put forward by Dr. S.J. Holt (1985) at the London hearings of the Royal Commission.

While there are other reasons, esthetic or moral, that can be put forward to support a cessation of sealing, this approach seems to be too dramatic and scientifically less than fully justified as a solution to the undoubted problems of resource management. The dangers arising from uncertainty and from a continuation of an unmodified management policy have to be matched against the ability to collect new information and to mod-

ify management practices. Sealing practised at anything like the 1980 level would represent a long-term risk to the stocks only if it were continued for a long time without adjustment to the allowable catches. Provided that large-scale sealing is accompanied by a program to monitor the stocks, and a willingness and ability to act on the results of the monitoring program rapidly enough to correct and reverse any exploitation-induced decline in those stocks, the risk of the decline becoming serious enough to threaten the stocks should be small.

To meet these conditions seems entirely feasible. The existing management process includes annual reviews of all measures, including the size of quotas. Monitoring could be achieved by any of the methods already used to estimate the population, though, because of possible bias, tagging could be less useful than other methods. The survival index would also be a poor monitoring tool if no deliberate manipulation were made to the catches. However, deliberate year-to-year changes in catches, such as the taking of twice the allowable catches of pups in one year, followed by a zero pup kill in the following year, could serve as a good monitoring tool. If the example given were taken, it would be possible to obtain good, independent, estimates of population size from each pair of years unless the catch was a very small part of the total pup production.

Probably, though, direct aerial surveys of pup production would be the most appropriate monitoring tool. As these surveys cannot result in any large degree of overestimation (although they may result in under-estimates), they are likely to be acceptable to the groups concerned about possible risks arising from overexploitation. Since the chief purpose of a monitoring program is to detect trends in population size rather than to establish absolute population figures, some degree of bias, provided it is kept constant by maintaining the same survey procedure, would be acceptable. It has been pointed out (Berkson and DeMaster, 1985) that unless the population composition is stable, which that of harp seals is certainly not at present, the trends in pup population, which is the population segment generally surveyed, will not be exactly the same as trends in the total population. The difference, however, seems most unlikely to invalidate the use of pup surveys as a monitoring tool.

Conclusions

The harp seal population has been heavily exploited for more than a century, and this exploitation has depleted its population to a point well be-

low its original level. In particular, the very large annual catches of about 300,000 animals taken in the post-war period and up to about 1970 led to a serious decline in population levels. The annual number of pups born, which is the number easiest to estimate, is about 300,000–400,000, corresponding to a total population of well over one million harp seals and likely about two million.

The magnitude of the sustainable yield will depend on the age of animals killed, with one adult being reckoned the equivalent of about two pups, and on the values of the population parameters, several of which, especially the natural mortality rate, are not known at all precisely. The sustainable yield, if the catch is taken as pups, is probably about half the total production rate.

The catches since 1972 have generally matched the quotas set, which have corresponded to the general conclusions of the scientific advisers, though in some years, notably close to 1975, there was considerable disagreement among scientists. Fortunately, although the more pessimistic conclusions were not unrealistic on the basis of information then available, they have been proved to be too pessimistic. Currently available information suggests that catches taken since 1972 have been at or below the replacement yield, and the stock has probably increased. It is possible that it has decreased, but in either event the change has been small and impossible to demonstrate directly on the basis of current information about population size.

There is no complete agreement on a target level of population size for harp seals. The MSY level provides an initial reference level, but it may not provide the best ultimate target because of differences in interest between those who want a large population and those who want a small one, for example, in order to reduce gear damage. The present population abundance is probably below that giving the MSY. If it is desired to increase the population in order to bring the stock to the MSY level or for any other reason, then catches somewhere near recent levels, that is, annual quotas on the commercial hunt of about 170,000 animals, incorporating the recent balance between pups and older animals, would probably achieve this aim. Monitoring the harp seal population would be necessary to determine whether this objective is being achieved, and catches would need to be reduced if, in fact, the population is not increasing. If there is a wish to be certain of an immediate increase in population numbers, more conservative quotas would be necessary.

If significant catches of seals are to be made, it is essential that the numbers of seals are regularly monitored. The best method of monitoring the harp seal population, and the only feasible one in the absence of significant exploitation, is the use of ultraviolet photography or other techniques to make direct surveys of the pups and adults on the breeding patches. A repetition of earlier surveys is highly desirable, if possible involving statistical techniques to reduce the variance of the estimates obtained.

Since 1983, catches have been small and seem likely to remain low for the foreseeable future. The abundance is therefore increasing, perhaps by about 5% per year. The exact rate is uncertain, and if the impact of harp seals on fish stocks becomes a serious issue, regular monitoring of the abundance will be needed.

Hooded Seals

Introduction

The hooded seal is a large seal, two to three times the weight of a harp seal and with a similar life history and distribution. It breeds only in three areas of concentration: the West Ice to the west of Jan Mayen Island, the Front to the northeast of Newfoundland, and Davis Strait (Figure 21.6). The pups are born on pack ice, where they experience an extremely short period, lasting about four days (Bowen et al., 1985), of intense suckling before weaning. After breeding the western Atlantic hooded seals migrate to the north and east, and summer off the western and southern coasts of Greenland. Sealers take both adults and young (bluebacks) in the breeding concentrations, largely as part of the harp seal hunt, and all ages are taken in the summer off Greenland.

Hooded seals begin breeding between three and five years of age and thereafter produce one pup each year, with few exceptions. Maximum lifespan is about 30 years. Little is known about the feeding habits of hooded seals, partly because most samples have been collected while seals are on the breeding grounds, where they seem not to feed. Available data suggest that they feed at a greater depth than most other seals and consume rather larger animals. Food items that have been identified include squid, redfish and Greenland halibut.

Figure 21.6
Distribution of Hooded Seals

Source: King (1983).

The relationship between the groups breeding in different areas is unclear. Breeding in Davis Strait may be erratic, involving considerable exchange with the Newfoundland breeding group. Interchange between the east Atlantic (Jan Mayen) and the west Atlantic (Davis Strait and Newfoundland) is undetermined, but has been considered to be slight (Sergeant, 1974, 1979), though the most recent morphological studies (Wiig and Lie, 1984) are consistent with significant mixing. Seals tagged in

Newfoundland have turned up on the main moulting grounds in Denmark Strait, off the southeast coast of Greenland, but there appears to have been no movement of tagged seals between breeding grounds (Sergeant, 1978; Kapel, 1982; Øritsland, 1976). For the present purpose it seems best to treat the west Atlantic (i.e., Canada, Davis Strait and west Greenland) separately from the waters to the east of Greenland. This treatment might slightly underestimate the catches from the western stock in years when large catches were taken in Denmark Strait. Commercial sealing has, in fact, been stopped there since 1960, following evidence of a decline (Rasmussen, 1960).

History of Catches and Management

Significant subsistence catches have probably been taken around Greenland for a long time, though data on total catch or species breakdown are not available for the years before 1939. Northward movements of seals from the Newfoundland breeding area take most of the animals to the east side of Davis Strait; catches in arctic Canada appear to be very small. Statistics of catches from the west Atlantic since 1946 are summarized in Table 21.6. Because of their different impact on the dynamics of the population, the catches of pups and older animals have been kept separate.

The biggest catches have been taken in the commercial hunt on the breeding patches around Newfoundland and in the Jan Mayen area. Until the 1940s, hooded seals were taken incidentally to the harvest of harp seals, which, since it was more concentrated, attracted the higher hunting pressure, though catches of the two species followed similar trends. Since the 1940s, the skin of the young hooded seal (blueback) has attracted a premium price, and the intensity of exploitation of the two species has probably been similar.

At the beginning of this century commercial catches in the western Atlantic off Newfoundland were high, reaching a peak of close to 62,000 seals in 1901. Catches declined in the 1920s and 1930s to 1,000 seals annually, but picked up from the mid-1940s to a peak of 27,000 in 1966. Since then annual catches have amounted to a little over 10,000 until, with the collapse of the market, they dropped to almost zero in 1983. During this time there has been a decrease in the proportion of older animals included in the total catch.

Until 1973, there were no regulations governing the number of seals that could be killed, but in 1974, a total allowable catch (TAC) of 15,000 animals annually was introduced. The scientific basis for this number is ob-

Table 21.6
Catches of Hooded Seals in the Northwest Atlantic, 1946–1985

Year	The Front[a]					West	Grand
	Canada	Norway	Pups	Adults	Total[b]	Greenland	Total
1946–50	6,507	355	4,457	2,405	6,862	–	–
1951–55	2,374	3,598	4,442	1,530	5,972	–	–
1956–60	818	5,633	3,747	2,704	6,451	757	7,208
1960–64	1,104	4,055	3,124	2,035	5,159	1,066	6,225
1965–69	351	10,901	5,930	5,322	11,252	1,720	12,972
1970–74	847	9,413	6,176	4,084	10,260	1,952	12,212
1975	5,385	10,226	7,646	7,965	15,611	2,900	18,511
1976	3,867	8,518	6,540	5,845	12,385	3,316	15,701
1977	6,044	6,049	8,970	3,123	12,093	3,170	15,263
1978	4,189	6,315	7,966	2,538	10,504	3,635	13,275
1979	6,819	8,306	11,948	3,177	15,125	3,612	18,737
1980	7,409	5,707	11,153	1,963	13,116	3,779	16,895
1981	8,309	5,367	10,661	3,015	13,676	3,745	17,421
1982	5,831	4,562	7,757	2,636	10,393	4,398	14,791
1983	128	–	–	128	128	4,155	4,283
1984	444	–	–	–	444	2,692	3,136
1985[c]	452	–	219	233	452	–	–

Source: 1946–1967: ICNAF (1970).
1968–1978: ICNAF (1971a, 1971b, 1972, 1973, 1974, 1975, 1976, 1977, 1978, 1979, 1985).
1979–1982: NAFO (1981, 1982, 1983, 1984).
1983–1984: Moulton (1986).
1985 : Canada, DFO (undated).

a. Includes some animals taken in the Gulf, which was the result, in part, of differences in boundaries established by NAFO and by the Seal Protection Regulations.
b. Includes animals of unknown age.
c. Preliminary data for Newfoundland only.

scure and may have been no more than the opinion that the 1966 kill of more than 16,000 pups plus about 11,000 adults had been too high. In 1975 and 1979, the total Canadian and Norwegian catches, amounting to 15,611 and 15,125 seals respectively, slightly exceeded this quota, but in other years the catches were well below the quota.

In 1977, a regulation was set limiting the catch of adult females to no more than 10% of the total, and this percentage was reduced to 5% in 1979. The percentage of adults in recent (1980–1982) Canadian and Norwegian catches was stated to be 19% and 20% respectively, with the female component far below 5% in both cases (Canada, DFO, 1985, Appendix VIII, p. 14). The statistical base for this statement is not given.

The catches at Greenland seem to have fluctuated (Kapel, 1985). At the end of the 19th century, catches were as high as 10,000–15,000, and they were also relatively high, amounting to 6,000–8,000, in the period 1916–1920 (Kapel, 1978). Catches fell to a low level of 500–1,000 about 1950, but they have increased in recent years to about 4,000. In considering the impact on the stock, a figure for seals killed but not retrieved, should be added. Kapel (1985) noted that these losses are considered "high" at the beginning of the season, and "low" later, but believed that any figures representing actual percentages would be guess work.

Kapel (1985) also discussed likely trends in the effective effort devoted to hunting hooded seals in Greenland, taking account of such circumstances as growth in total population, increased proportion living in "townships", increased attention given to fishing for cod or other fish, and changes in hunting techniques. He concluded that the total number of active seal hunters did not change much during the period 1921–1972, but did not attempt to reach any conclusion on trends in effective hunting effort.

Compared with catches of harp seals, those of hooded seals seem to vary more, both from year to year and from decade to decade. Several authors (e.g., Vibe, 1967; Rasmussen, 1960) consider that environmental changes such as differences in the distribution of pack ice, and especially the higher water temperature at west Greenland in the 1930s, have had a major influence in bringing about these changes. This influence may relate more to the distribution of seals and their apparent abundance on established hunting grounds, than to true numbers.

Estimates of Abundance

Only two methods have been successfully used to estimate hooded seal numbers: the survival-index method (Sergeant, 1977) and aerial surveys (Hay and Wakeham, 1983; Hay et al., 1984; Hay et al., 1985). Some tagging has been done, but not at an intensity to provide useful estimates of abundance.

The survival index was applied to the year-classes of 1966–1971; during this period pup catches varied substantially, numbering between 1,200 in 1968 and 16,800 in 1966. These catches correlated well with the observed number of survivors, estimated as the percentage of five-year-old seals in the years 1970–1976. Applying the method directly, the regression of survival index on pup catch gave an intercept (i.e., an estimate of pup production) of about 27,000 (Sergeant, 1977). The period of analysis is so short that the adult population probably did not change much, and thus some of the criticisms of the method, such as that made by Beddington and Williams (1980) do not apply. Some correction downwards should probably be made to allow for errors in age determination. However, the numbers of pups actually killed in 1966 provides an absolute lower limit of the production in that year. Because the young are scattered it is highly unlikely that the kill actually approached 100% of the production. It can therefore be said with a fair degree of confidence that the production of pups at the Front in 1966 numbered 20,000–25,000 and possibly higher, but there is little likelihood that it was significantly lower. The usefulness of this conclusion to present-day management is, however, greatly reduced by the problems of projecting population numbers forward with any degree of reliability.

Hooded seal pups and adults on the breeding ice can be relatively easily seen and counted from the air, either visually or by means of photographs. To transform the numbers seen into absolute numbers is difficult for two reasons: the difficulty of executing a survey that covers adequately the scattered population, and the fact that the seals on the ice, and therefore visible, represent only a (possibly small) proportion of the total population.

Both problems have been examined during the 1983 and 1984 surveys of the Front and Davis Strait breeding areas (Hay and Wakeman, 1983; Hay et al., 1984; Hay et al., 1985). The problem of surveying was dealt with through a modification of standard surveying techniques (e.g., Caughley, 1977); this meant dividing the whole region in which any pups existed into a patch or patches of high density (10–100 pups per sq km) which were surveyed intensively and a much larger, low-density area of scattered pups.

Pups on the ice pass through clearly distinguishable stages – new-born, thin blueback, fat blueback – during all of which the mother is normally present – and solitary, which commences after weaning, when the mother has left. Since all pups are normally weaned by five days of age, the total length of all these stages is short. Thus, although the spread of birth dates is short, there is not one moment when all the pups have been born, but none have left the ice. For this reason any one count of pups will be less than the total pup production. By making counts on a number of days, observing the proportion of each stage, and taking account of the duration of each stage, the pattern of births on each day, and hence the total number of births, can be estimated. Hay et al. (1985) estimate pup production in 1984 as follows (with confidence limits in brackets):

Front: scattered pups	7,400	(2,700 to 14,400)
Front patch	54,700	(37,200 to 72,200)
Davis Strait patch	18,590	(13,750 to 23,440)

For the scattered pups on the Front and the Davis Strait patch it was not possible to estimate the pattern of production over time, and the figures given are for single surveys. They will therefore be biased downwards.

The surveys made on the Front in 1983 were not comprehensive enough to allow for estimates of this type. Estimates of the actual numbers present in one or another of three identified patches at the times of three surveys were as follows (Hay et al., 1984):

Middle patch	18 March	2,504	(1,312 to 3,696)
North patch	24 March	2,589	(309 to 4,870)
Middle patch	25 March	2,153	(– 489 to 4,796)

The negative lower confidence limit is clearly inappropriate; it was obtained by applying equal arithmetic limits above and below the central value.

Hay et al. (1984) note that their final 1983 estimate of about 5,000 seals, which was obtained by adding the two patches, is tentative at best. Certainly, since it contains no estimate for the southern patch or for the pups outside the patches, and no correction for pups not yet born, or for pups which have already left the ice, it must be an underestimate. The two latter factors, however, as judged by 1984 experience at the Front, would go only a small part of the way to explaining the difference from the 1984 figure of about 62,000 pups produced at the Front. Examination of the results shows that the big difference is in estimated size of patches, while estimated density within patches is roughly similar in the two years.

Estimating patch size seems to be difficult (Hay et al., 1984, Table 8), but the various surveys carried out in 1984 indicated patch sizes of a few hundred sq km (a population of up to 1,025 animals was estimated from the incomplete fixed-wing survey of March 20), while those made in 1983 varied between 32 and 106 sq km.

It is impossible that the total west Atlantic population can have increased by more than a few percent between 1983 and 1984, and while there may have been changes in the distribution and proportion of the total Atlantic population breeding on the Front, the most likely explanation of the difference between the two years is that patches, or parts of patches, were missed in 1983.

The 1984 central estimate is also considerably larger than that obtained for 1966–1971 by the survival-index method. Hay et al. (1985) conclude that the seal population has increased during the past 20 years. However, bearing in mind the wide confidence limits in both estimates and the possible different procedural errors in the two approaches, it would seem safer to consider the figures as strong, but not conclusive, evidence of an increase. Other evidence bearing on a possible population increase is presented in later sections.

Estimates of total population can be extrapolated from figures of pup production in the same way that has been done for harp seals. Since the population parameters for the two species are similar, the same ratio of 4:1 may be used as a reasonable approximation. This would suggest, from the 1984 estimates of pup production, a total west Atlantic population of 300,000 animals.

Population Parameters and Sustainable Yield

Much less is known about the vital parameters such as mortality and reproductive rates of hooded seals compared with harp seals, though they seem to be broadly similar. Females become mature when they are between three and five years old and produce pups a year later. Jacobsen (1984) gives a mean age at first parturition of 4.9 years based on data collected in 1972–1978 on the West Ice (Jan Mayen) grounds, and Born (1980) suggests a mean age at maturity, estimated from samples collected at south Greenland, of 3.2 years, which corresponds to a mean age at first parturition of a little over 4.2 years.

Born (1980) estimated a fertility rate of 91.5% and Øritsland (1975) an ovulation rate of 95%; the latter rate might be expected to be somewhat higher. There is no evidence to indicate differences in reproduction rate or age of maturity from area to area or from year to year. It would be reasonable to expect density-dependent responses similar to those for harp seals, but data are not good enough to detect them if they exist.

Hooded seals live up to 30 years or slightly beyond. Total mortality rates have been estimated from catch curves or from mean age. Even if sampling is unbiased, which is probably the case for fully mature age groups, these methods give biased estimates if there is a trend in recruitment or mortality rate, and the estimates refer to the average mortality at some period in the past, rather than to the time of sampling. Interpretation of results needs caution.

Published estimates of total mortality are $Z = 0.19$ to 0.35, from samples taken in the years 1971–1976 at the Front based on catch curves (Winters and Bergflodt, 1978); $Z = 0.22$ for the West Ice, based on mean age (Flipse and Veling, 1981, quoted in Canada, DFO, 1985); and $Z = 0.142$ (confidence limits 0.115–0.166) (NAFO, 1985) from a sample of 147 females taken in Davis Strait in 1984. It is also possible to use the age composition of samples taken on the West Ice presented by Jacobsen (1984) to derive estimates using the catch-curve method. The combined Norwegian samples for 1972–1978 (Jacobsen, 1984, Table 2) gave a good log-linear fit for ages 6–20, corresponding to $Z = 0.20$. Since it is more likely than not that over the relevant years (roughly 1955–1968) year-class strength was declining, this may be an underestimate of the actual total mortality in the mid-1960s to mid-1970s.

These estimates are too few, too imprecise, and too uncertain as to the years in which the estimated mortalities occurred to make useful comments on the differences in mortality between areas or periods, though it is tempting to ascribe the relatively low estimate for Davis Strait to lower fishing mortality on that group of seals. The ICES working group report (ICES, 1983) noted that "estimated mortality rate levels decreased substantially in most recent years, and this is consistent with the reduced kills of breeding females since 1977." The basis for this statement is unclear. It would be surprising if reduced kills after 1977 would be apparent, through the use of catch curves or similar methods, in samples taken as early as 1980.

The fishing mortality can be estimated, independently of age data, as the ratio of catches to total numbers for all or any specified part of the popu-

lation. Winters and Bergflodt (1978) used this method to estimate the fishing mortality on females in 1966–1971. Their estimate of $F = 0.135$ has been challenged by the U.K. Nature Conservancy Council (NCC, 1982) on the basis that too low a fertility rate had been used. In view of the doubts about population size (and in some cases, the size of the catch), not much precision can be expected from this approach. It does show that unless population sizes were much greater than believed, fishing mortality on the older animals is significant, perhaps amounting to 0.10 or more. By the same argument, the estimates of total mortality are significantly larger than those of natural mortality. No direct estimate of natural mortality is possible, and it remains reasonable to use a similar range of values (about 0.10 or a little higher), as used for harp seals.

These parameter estimates are hardly good enough to provide the basis of an attempt to estimate sustainable yield, but Table 21.8 of Appendix 21.1, which covers many of the more likely combinations of parameters for hooded seals, can be used to provide an indication of the sustainable yield as a proportion of total pup production. This proportion will depend critically on the ages of seals harvested. If the harvest is taken wholly as pups, it might (if $M = 0.10$, and the age at maturity is 4) be some 57% of the production, but with the same parameters the sustainable harvest of adults would be only 28%.

The Present Situation

In 1983, it was possible, and probably desirable, to take a gloomy view of the state of the hooded seal stocks. No good estimate of population abundance was available for the stock since about 1971. Catches were high, and though there were no clear signals of impending stock collapse, it was quite possible that the stock was low, and declining rapidly.

The present situation is quite different. The results of the 1984 aerial survey make it clear that the population is much greater than many people had feared. Present (1983–1985) catches, following the collapse in the market, are obviously less than the sustainable yield (with a small reservation described below). The important question is whether the stock was increasing under the catch rates occurring about say, 1980, and in particular, whether the quota of 15,000 seals was reasonable.

A comparison of the estimates of pup production, of approximately 25,000 in the period about 1970 (from survival index) and approximately

60,000 in 1984 (from surveys), strongly suggests that the population had increased during the intervening period. An increase of roughly twofold during the same period is also suggested by the trend in catches at west Greenland; these catches were up from fewer than 2,000 annually before 1970, to over 4,000 in 1984. Kapel (1985), in his analysis of trends in catches, stresses the problems in evaluating the trends in effective hunting effort and hence the dangers in using annual catches as indicators of trends in seal abundance. However, his analysis does not identify any changes that would suggest a twofold, or greater, increase in hunting effort. The trend in different areas (Kapel, 1985, Figure 3) indicates that increases occurred in all areas, but were proportionally greater in the northern areas and possibly earlier in the south than in the north. This would suggest that changes in distribution could have been a factor. Nevertheless, the data are more supportive of an increase in abundance than of no significant change or a decrease.

Comparison of catches with likely values of sustainable yield, which should take into account the proportion of different ages and sizes in the catch, are made difficult by the non-availability of a breakdown of catches by age and sex. Though there is no question of a large surplus of males, as may arise in the case of fur seals or sperm whales, an imbalance in the sex ratio in the 1970s, as a result of heavy exploitation of adult females in earlier years, may have allowed significant catches of adult males to be taken for a few years without significant effect on the stock.

Between 1978 and 1982, averages of just under 10,000 pups and 2,600 adults were taken by Canadian and Norwegian sealers, and of 3,800 seals of all ages at Greenland. Assuming, for the purposes of rough calculation, that one adult seal is equivalent to two pups (which may be an overestimate if significantly less than half the adult catch is female), and that one seal caught at Greenland is equivalent to 1.5 pups, the total annual average was equivalent to about 20,900 pups, that is, about 30% of the central 1984 estimate of the total pup production on the Front. This rate of harvesting is sustainable under some, but by no means all, of the feasible combinations of population parameters. That is, it is possible, though far from certain, that the population was increasing under the pattern of exploitation existing in the years immediately preceding the collapse of the market for skins in 1983. Similar calculations can be applied to earlier periods. For example, in the period 1960–1964, the catches, in round figures, were 3,000 pups and 2,000 adults at Newfoundland and 1,000 at Greenland, equivalent, on the assumption made here, to 8,500 pups, that is, about 35%–40% of the estimates of pup production. With the obvious exception of 1966, when over 16,000 pups and

nearly 11,000 older animals were killed, it is possible, perhaps even probable, that the catches were below the sustainable yield over most of the post-war period.

In summary, therefore, there are three pieces of evidence bearing on changes in abundance: the difference between 1966–1970 and 1984 estimates, catches at west Greenland, and estimates of sustainable yield. The first points strongly and the second moderately to an increase, and the third is neutral. The most reasonable interpretation is that abundance has increased, although this point is not conclusive. Under 1983–1984 conditions of low catches, it is almost certain that the stock is increasing. The exact rate of increase is uncertain. In the absence of information on density-dependent effects, no estimate can be given of the level to which the abundance might tend.

A complication is that there is evidence from the long-term fluctuation in catches, that even in the absence of exploitation, the apparent abundance of hooded seals is not constant, but subject to variations over periods of several decades. These changes may reflect only changes in distribution, but to the extent that they reflect real changes in abundance, trends resulting from natural changes may partially or wholly overrule the effects of changing hunting practices. For this and other reasons, it is difficult to make a quantitative comparison between the present abundance and that that would occur in the absence of any exploitation, or that would correspond to any target level such as maximum sustainable yield (MSY).

Effects of Management

The commercial hunt for hooded seals has been carried on largely as an adjunct to the more significant hunt for harp seals, as has the management of these animals. The distribution and migration patterns of hooded seals are similar to those of harp seals, and the early management of both species had to wait for the establishment of the necessary international mechanisms. When the first quotas were set for harp seals in January 1971, it was judged that there was insufficient information for sound scientific advice, and no quota was recommended for hooded seals. The first quota was set at 15,000 for the 1974 season, as recommended by the 1973 meeting of the scientific advisers of the International Commission for the Northwest Atlantic Fisheries (ICNAF).

In the next few years scientific attention was focused on the harp seals, and although a meeting of the Canadian sealing industry on 5 December 1975 expressed concern about the hooded seal and suggested a reduction in quota to 10,000 animals, the quota has remained at 15,000. Except in 1975 and 1979, when catches of 15,611 and 15,125 hood seals were made, the actual catches (excluding the Greenland catches, which were not included in the regulations) have been well under the quota, averaging a little over 12,000 between 1974 and 1982. In 1983 and later, catches fell to nearly zero. This pattern differs from that of harp seals, of which the catches by Norwegian and large Canadian vessels were usually close to the quota. It seems that the regulations had little effect on catches, though they may have discouraged any larger-scale development of catching hooded seals.

Conclusions

As a result of the 1984 aerial surveys, significant additional information has been collected on hooded seals that allays most of the fears expressed recently. It is possible that the stock was increasing even before the drop in catches in 1983, but there is considerable uncertainty about the value of the sustainable yield. It is far from certain that TACs of 15,000 or 12,000 seals were sustainable, even if most of these animals were taken as pups. It would be sensible, if hunting recommences, to ensure that the stock does not decline by setting more conservative figures, at least pending the gathering of further information. More explicit attention should also be given to the ages of seals making up the TAC. Further aerial surveys of the breeding grounds would be highly desirable.

Grey Seals

Background

The grey seal is an animal of temperate waters. It is found on both sides of the Atlantic, though the largest numbers – about two-thirds of the total population – are found off the coasts of the United Kingdom. It is a seal of moderate size but the males are rather larger than the females; the males average about 230 kilograms as compared with an average of 150 kilograms for the females.

The grey seal breeds in colonies, which are often quite small; these colonies mostly exist on islands and usually in rocky areas, though there are colonies on the sandy areas of Sable Island and on Scroby Sands in the United Kingdom. This species also breeds on fast ice in Northumberland Strait and the Gulf of St. Lawrence. The young seals are born in January–February on the west Atlantic coast, though rather earlier (September–January) in the east. After the breeding season there is considerable dispersion from the breeding colonies, though there is little suggestion of directed migrations (Mansfield, 1967a).

Though grey seals are found on both sides of the Atlantic, there does not seem to be any interchange among colonies on both sides of the ocean. On the west side they have what is now a large breeding colony on Sable Island, and they also breed in the Magdalen Islands and in other locations in the Gulf of St. Lawrence and the Atlantic coast of the Maritimes. There is also a small breeding colony on Nantucket Island (Mansfield, 1967a). They are found in summer as far north as northern Labrador (Figure 21.7). It is believed (CAFSAC, 1984) that there is a single population in the northwest Atlantic, with considerable mixing between the Gulf and Atlantic components. Recoveries of grey seals tagged on Sable Island show wide dispersion of the species over much of its reported range, but this finding could still be consistent with fairly clear separation of breeding groups (CAFSAC, 1983). The ratio of tagged (mostly Sable Island) to untagged (mostly Gulf of St. Lawrence) animals showed a very high separation of pups, and a moderate distinction in older animals, between those inhabiting waters inside, and those outside, the Gulf (Zwanenburg, 1984).

Grey seals can live for up to 40 years. They feed mostly on fish, including herring, flounder, cod and other commercial species (Mansfield and Beck, 1977). Some records include appreciable quantities of salmon (Rae, 1968), but these may be biased as they relate mostly to seals killed near salmon nets. In fact, recent studies made in the United Kingdom and based on the examination of faeces suggest that sand eels and other small fish are a more important element of the grey seals' diet.

Grey seals are of low economic value, and these animals have not been the subject of recent commercial exploitation (Mansfield, 1967a). Historical records indicate that they were probably heavily exploited in the 17th and 18th centuries, both on Sable Island and in the Gulf (Chantraine, 1980), and reduced to very low levels from which they are only now recovering. Since 1967 they have been subject to a government cull program and since 1976 to killing by fishermen under a bounty program (Mansfield

and Beck, 1977). Taken together with small research kills in some years, the numbers killed by humans and officially recorded have increased fairly steadily, rising from 200 in 1967 to over 3,000 in 1983. However, the number of kills decreased after 1983 when the cull program was discontinued. In 1984 and 1985, research and bounty kills (combined) numbered 580 and 446 respectively (Hoek, 1985; Beck, 1985). Despite these losses, the grey seal population appears to have increased in recent years.

Figure 21.7
Distribution of Grey Seals in the Western Atlantic

Source: King (1983).

Current Status

The number of grey seal pups produced on Sable Island, where conditions are unusually favourable to direct counts, has been estimated annually (with a couple of exceptions) since 1962 by this method (Mansfield and Beck, 1977; Canada, DFO, 1985, Appendix LVII). Numbers of pups have also been estimated from tagging experiments conducted on Sable Island and in the Gulf of St. Lawrence.

The Sable Island counts show a steady increase in numbers of pups from about 350 in 1962, to nearly 6,000 in 1984 (Mansfield and Beck, 1977; Zwanenburg et al., 1985). A rough log-linear plot indicates that this increase has taken place at a fairly constant exponential rate of 13% per year, with no sign of any slowing down. The difference between this rate and the 12% rate mentioned in some CAFSAC documents is not significant.

Between 1977 and 1983, nearly all the grey seal pups born at Sable Island were tagged (in all, nearly 22,000); in addition, some 1,300 pups were tagged in the Gulf up to 1983, and a further 1,441 were tagged in 1984. Estimates of total pup production were obtained from comparing the ratio of tagged to untagged animals in later catches, particularly those made by hunters. Corrections have been made for tag losses, and consideration has also been given to the possibility of tagged-induced mortality (which is probably small). The resulting estimates from the pre-1984 tagging experiments (Zwanenburg, 1984, Table 7) were as follows:

Tagging Year	Estimates of Pup Production	Confidence Limits
1977	15,825	11,026–24,904
1978	11,180	8,596–15,135
1979	14,754	10,521–21,986

This method, however, depends on equal mixing of tagged and untagged animals. Figures 2 and 3 of Zwanenburg (1984) show this equal mix does not occur. Though the animals aged one year and older are better mixed than pups, there is still a big difference in the ratio of tagged to untagged seals taken in the inner Gulf (about 0.20) and those taken off the eastern coast of Nova Scotia (about 1.0). Since the observations cover most of the distribution of grey seals, an upper bound to total production can be obtained by using only the returns from the inner Gulf of St. Lawrence, but it is difficult to set a lower bound. Without more detailed information on tag re-

turns, especially the returns from non-Sable Island tags, it is difficult to quantify these bounds. Casual inspection of the data suggests that the upper bound may be only slightly higher than the estimates given above (i.e., about 15,000), and the lower bound (based on tagging data) may be only slightly higher than the Sable Island production. These estimates would be consistent with the tagging results if most Sable Island seals stayed offshore or off Newfoundland, and if only a few hundred animals moved into the Gulf to mix with a few hundred locally born seals.

Another estimate of the Gulf pup production, based on the ratio of animals, seen on Sable Island or killed in the bounty programs, which were either tagged in the Gulf or carried no tag, has been given by Zwanenburg et al. (1985). The condition of uniform mixing of tagged and untagged animals in this data set is much more likely to have been satisfied; in fact, four independent samples gave rates that were not significantly different, averaging about 1:4, equivalent to a 1984 Gulf production of 6,336 ± 2,106 animals.

Other estimates of the production of pups in areas other than Sable Island are based on aerial surveys, and on the culling and tagging programs. Though conditions in these areas are much less favourable for direct counts than conditions on Sable Island, aerial surveys have been made both during and outside the breeding season. The survey made in January 1984 estimated that there were 2,650 pups in Northumberland Strait (Clay and Nielsen, 1984), which seems to be the main breeding ground in the Gulf of St. Lawrence. Lower limits to the total pups born in the Gulf are based on the numbers killed in the cull or tagged. In 1982, 654 pups were tagged, and 1,663 were culled; in 1983 at least 1,610 pups were killed or tagged, and in 1984, 1,441 were tagged; this latter number represented as many pups as could be found. Nevertheless, untagged 0+ animals exist in appreciable numbers. Out of a sample of 48 pups taken later in 1984, 35 were not tagged. Sergeant et al. (1984) estimated a pup production of 6,004 animals (for 1984) and 3,912 (for 1982) based on these returns of 0+ seals tagged away from Sable Island, but the numbers returned are too few, and the problems of incomplete mixing are too large to conclude more from these data than that the pup production away from Sable Island is larger, and probably substantially larger, than the numbers tagged or culled. Sergeant et al. (1984) consider where the "missing" pups might have been born, but without more concrete evidence on the likely numbers of pups not accounted for, this exercise is not worth pursuing very far.

Estimates of the total grey seal population can be obtained by extrapolation from the pup estimates, using figures for mortality and other

pertinent rates. It would be difficult, on the basis of the present information, to improve on Zwanenburg's (1984) estimate, which he bases on Leslie matrix analysis, though he stresses the weaknesses in the results. Zwanenburg estimated that in a stable age composition, age 0 animals should make up 17.8% or 17% of the total, depending on whether the population is increasing at a rate of 7% or remaining constant. This is to say that the total population is roughly six times the number of pups.

Given that in 1984 nearly 6,000 pups were known to have been born on Sable Island, and that 1,440 pups were tagged in the Gulf, the minimum 1984 pup production, allowing for only a handful of other births, was some 8,000 animals. A reasonable upper bound is difficult to set, but the unproductive consideration of the location of "missing" pups suggests that undetected pups were not very numerous, probably amounting to no more than those born on Sable Island: say an upper bound of 12,000 for Sable Island and the Gulf together. These numbers correspond (rounding the lower and upper bounds down and up) to total grey seal populations of 40,000 to 75,000. These figures, especially those representing the lower bound, are lower than most quoted figures, but the latter seem to take too much account of the unreliable estimates based on the Sable Island tagging. The most recent results of tagging of pups in the Gulf (Zwanenburg et al., 1985) suggest a total pup production of 12,000.

Most documents that deal with the grey seal population take it for granted that the population is increasing, but quantitative evidence of an increase in pup production exists only for Sable Island. CAFSAC (1984) noted that the rate of increase in the Gulf component is not fully known, but it seems closer to the fact to say that for the moment, it is not even known whether the pup production in the Gulf is increasing. There is plenty of anecdotal evidence from fishermen and others that there are now more grey seals along most of the Canadian east coast than there were 10 or 20 years ago, but this change could be accounted for by the increased numbers of grey seals breeding on Sable Island.

Future Prospects

The present rate of increase, whether at 13% per year or at some lower rate, cannot continue for ever. Even at a rate of increase of 7% per year, the population would double each decade, and increase by a thousandfold, to some tens of millions, in about a century. The question is, therefore: When will the growth cease (or reverse itself), and at what level of

abundance? Put differently, what factors are causing the present increase, and when, and at what population level, will these factors cease to operate, or when will other factors arise to balance them?

On the east side of the Atlantic the grey seal inhabiting waters around the United Kingdom is also increasing, at about 6%–7% per year. This increase has been interpreted as the recovery to some earlier level of a population that had for a long time been undergoing reduction by traditional subsistence hunting at many of the breeding sites (Bonner, 1982). The past effect of humankind on grey seal stocks in the western Atlantic is unclear. During the present century the numbers of these animals officially recorded as killed in culls and bounty hunts only became significant at about the same time that their increase on Sable Island became apparent and was, in fact, a response to that increase. Previous to these culls there are few records of grey seals being killed, and indeed, few seals at all were recorded. Allen (1880), however, going back to what even in his time was ancient history, refers to Dodsley's 1761 translation of letters written by Charlevoix to the Duchess of Lesdigureves in 1721, describing what appears to be killing of grey seals in the Gulf of St. Lawrence. Chantraine (1980) indicates that they were heavily exploited in the 17th and 18th centuries. It may be that the low numbers of grey seals in the 19th and early 20th centuries were the result of earlier overexploitation.

The only published explanation for the increase in numbers of grey seals seems to be that of Brodie and Beck (1983), who attribute it to a decrease in large sharks in the northwest Atlantic. Though there is no good direct information on the numbers of large sharks in the northwest Atlantic, it is likely that these fish have decreased, as a consequence of the development of a directed shark fishery by Norwegian fishermen in the 1950s and, more recently, as the result of the increase of longlining for swordfish and large tunas, a process which produces large incidental catches of sharks. Sharks are known to be significant predators on grey seals off Sable Island (Brodie and Beck, 1983), though probably not elsewhere. The argument that a decrease in sharks is the cause of the increase in seals is therefore persuasive, though not conclusive. Sable Island lies in the middle of the fishing grounds for sharks, as Figure 1 of Brodie and Beck illustrates, but the other breeding areas of grey seals are well away from the shark areas.

However, the seals killed in the cull and bounty programs were taken exclusively in the Gulf of St. Lawrence and along the coast of the Maritimes (45% in Quebec, and 55% in the Maritimes), and thus these programs would be expected to affect the seals breeding on Sable Island less

than they would those breeding elsewhere. The future trends in shark population are difficult to project; the most reasonable assumption would be that as long as the swordfish longline fishery continues, the shark population will remain relatively low.

Another factor that will clearly affect future trends in the seal population is the number of these animals killed in culls or bounty programs. Two points should be made. First and obviously, the killing of say 1,000 seals will, in the short term, reduce the seal population by 1,000. Secondly, as long as the factors causing the present increase in the seal population continue, this reduction will be strictly temporary. The considerable kills made during the past 18 years have not stopped the continuing increase in the numbers of seals. Presumably, the current (1985) number of seals is lower than it otherwise would have been, but unless the cull is continued, the difference it will make by 1990 or 1995 will be very small. Thus the past culling is largely irrelevant to the future size of the stock. The effect of any future culling or bounty program will be discussed after a consideration of what might happen if no seals are killed by man.

The critical factor is the point at which density-dependent effects operate to counteract the forces currently increasing the seal population. On the Farne Islands in the North Sea, pup mortality is known to increase with pup density over the range of 20–100 young per 100 metres of accessible shore (Bonner and Hickling, 1971), but it is not known whether this is the only density-dependent effect, nor is it known whether it would apply at other grey seal colonies. It is possible that direct effects of crowding of this type could apply to the southern Gulf of St. Lawrence, especially in years of little ice, but not to Sable Island. No direct information seems to be available about stocks of grey seals in Canadian waters. All that can be said with confidence, therefore, is that in the absence of a cull, the present increase will continue, probably at a slightly increased rate, at least away from Sable Island, but that it will certainly not continue for ever. If the general belief is valid, that the sustainable yield curve has a maximum (MSY) at a high proportion of the unexploited stock, the density-dependent factors can be expected to begin to be effective rather suddenly. They may therefore be difficult to detect until the population gets quite close to the limiting abundance.

Cull Programs

The principle guiding a cull or bounty program is the same as that guiding a management program for sustained yield of an economically valu-

able resource. If the appropriate number of animals (adjusted as necessary to the age and sex of the kill) are killed each year, then the population will be maintained at its current level. If more or fewer than this number are killed, the population will decline or expand, ultimately to extinction or to the limits set by the carrying capacity of the environment. If the current population is not at the desired level (e.g., MSY), the numbers killed have to be adjusted for a short period.

If, therefore, a bounty or cull program is being considered on the grounds that the seal population is too large, it has to be planned on a continuing basis according to the standard sustainable yield calculation. In addition higher kills will be necessary for a period if the population is above the desired target level. At present this target level is not defined. A need for a cull has been expressed because of damage done by seals to fishing gear, consumption of commercial fish, and the transmission of parasites. For each of these circumstances, there is presumably a different optimum level of seal abundance which balances the impact on fisheries with the costs of control. These levels are at present unknown.

So far, no such calculations seem to have been made. Some existing proposals, such as that made in the October 1983 report of the Task Force on Seal Borne Parasites (Canada, DFO, 1983), lack any estimates of sustainable yield and seem to imply, in places at least, that culling would be a short-term exercise. The information is not available for making a good estimate of sustainable yield (i.e., the cull necessary to prevent further expansion of the number of grey seals), but for a population of about 60,000 animals which is expanding by some 10% annually, the sustainable yield (cull) would be about 6,000 animals. The actual numbers would be greater if the kill were concentrated on pups.

Summary and Conclusions

The grey seal population off Canada's east coast is believed to number between 40,000 and 75,000 animals; the upper part of this range is the more probable. The group of animals breeding on Sable Island is increasing rapidly, at a rate of about 13% annually. It is not known what is happening in the other breeding groups, though the population as a whole is almost certainly increasing. The reasons for the increase are uncertain, but they may include reduced predation by large sharks. There is no certain relation between the present population abundance and the equilibrium carrying capacity of the present environment or some of the standard target levels, such

as that giving MSY, but the population is well above the level at which there would be concern for its continuation, and it may be above the level that is readily acceptable to the fishing industry.

Harbour Seals

Background

Harbour seals are distributed widely, without any marked concentration, over much of the western Atlantic from Maine, off the Maritimes, Quebec and Newfoundland, and as far north as Ellesmere Island and Hudson Bay (Figure 21.8). Their habitat also extends into fresh water more than does that of most seals, for harbour seals have appeared as far up the St. Lawrence as Montreal (Bonner, 1979; Mansfield, 1967a). Their biology and population dynamics have been examined by Boulva and McLaren (1979). There is little evidence of long-distance movements, and information on the number of post-canine teeth (Boulva and McLaren, 1979, Table 2) suggests that there is a fair degree of distinction among groups. Harbour seals feed close inshore or in shallow waters, where they appear to take a variety of fish, cephalopods and crustacea, varying their diet according to the species available.

The small scattered groups typical of the harbour seal have not been subject to major commercial hunts, though in northern Canada the species is subject to significant subsistence hunting to provide meat and blubber for man and dogs, as well as for its skin. From 1927 to 1976, it was subject to hunting for a government bounty, which from 1949 required the submission of the lower jaw. This eliminated false claims based on grey seals or other material. The number of bounty claims fell at an approximately constant exponential rate of 8%–9% per year, from 1,000 pups and 300–400 older animals in 1950 to 200 pups and 50 older animals in 1967 (Boulva and McLaren, 1979). In that year, the reward was increased, and there was some resurgence in kills until 1976, when the bounty was discontinued. The number of pups killed is roughly equal to the number of bounty claims, or larger, since most pups killed are recovered, and there may be some claims on pups that have died naturally. According to data provided by Boulva (1973), however, only about 65% of the older seals killed are recovered, and so bounty claims should be increased by 50% to reflect the actual number killed (Boulva and McLaren, 1979).

Figure 21.8
Distribution of Harbour Seals in the Western Atlantic

Source: King (1983).

Population Numbers

Since harbour seals are often scattered in inlets or on small islands, they are difficult to count. The most thorough attempt at a census was carried out by Boulva (reported in Boulva and McLaren, 1979), who, on the basis of questionnaires, interviews and distribution of bounty kills, estimated a total population in eastern Canada (excluding the areas from Labrador northwards) of 12,700 in 1973, of which some 5,500 were in the Maritimes, excluding Sable Island. The latter figure compares with an esti-

mate of 10,000–15,000 in the same region in the 1940s, though that estimate is based on less extensive surveys conducted by Fisher (1949).

This evidence of a decline during the post-war period is consistent with the decline in the number of bounty claims. Boulva and McLaren (1979, Figure 17) show that between 1950 and 1966, the claims on pups and older animals showed an annual decline of some 8.2% and 9.4% respectively. They believed that these figures overestimated the true decline in seals, as a result of falling interest in hunting for the bounty. When the bounty was increased in 1967 reported kills increased, but not to the level of 1950. The decreases in reported kills that occurred between 1950–1952 and 1968–1971 were equivalent to annual rates of some 6% for pups and 3% for older animals. These figures agree with the 4% rate of decrease in population inferred from the differences between the surveys in the 1940s and 1973, which Boulva and McLaren considered reasonable. Such a decrease would imply, from the total 1973 census, the existence of some 28,000 seals in eastern Canada (excluding the northern part) in 1950. At that time bounty rewards were given for some 400 adults and 1,000 pups. Allowing for animals lost, this gives a total bounty kill of some 1,600 animals annually, or 6% of the population; this percentage is of the same order of magnitude as the supposed decrease in population.

A more precise analysis, based on reproductive and mortality rates, including an observed difference in mortality rates between areas of high and low hunting intensity, was made by Boulva and McLaren (1979). They concluded that the data were consistent with a decrease in population of 4% per year, caused entirely by hunting. They also considered that age of maturity may have showed a density-dependent response. There is no direct evidence for this in eastern Canada, but there is a difference of about one year between the heavily hunted populations in British Columbia and the less heavily hunted ones in eastern Canada. Under an assumption of density-dependence, Boulva and McLaren found a sustainable yield of 1.5%, that is, a rate of increase in the absence of hunting of 1.5% per year.

Since the bounty was discontinued in 1976, there is little quantitative information on harbour seal populations. It is reported (Canada, DFO, 1985) that fishermen are increasingly complaining about damaging and robbing of nets by harbour seals, and that the Sable Island population is increasing. Increased damage may be caused by the seals' greater boldness in the absence of shooting. There is anecdotal evidence of this response in the United States, following the enactment of the United States *Marine Mammal Protection Act of 1972*. Given that the current population of har-

bour seals is below its 1950 level and hence presumably below the carrying capacity of the environment, it would be expected to increase. However, the data recorded from 1950 to 1976 do not suggest that this rate of increase is likely to be large; the suggestion is that it would amount to no more than a few percent per year. On the assumption that the population decreased from 1973 to 1976, when the bounty was discontinued, and increased slowly thereafter, an informed guess at the 1985 population would be not far from the 1973 level, or around 13,000. All the information provided so far in this paragraph refers to the area south of Labrador. Very little quantitative information is available for the area farther north. Templeman et al. (1957) indicated that the biggest concentration of harbour seals in the whole Labrador-Newfoundland area was in south-central Labrador around Hamilton Inlet.

Farther north the harbour seal population is reported by Davis et al. (1980) to be sparsely and locally distributed. Mansfield (1967b) noted that because of this localized distribution, the population could, in places, be susceptible to pressure from local hunting, and that it appeared to have been eliminated from some places in Ungava Bay and Southern Baffin Island. Reported harvests of harbour seals in the Northwest Territories amount to only a few tens annually, but the species may not always be distinguished from ringed seals (Smith and Taylor, 1977).

Future Prospects

In the absence of hunting, the harbour seal population in the more southern areas might be expected to increase for some time. There is little information from which to estimate the limiting size of the population, or the degree to which this size might be changing as a result of environmental changes or human activities such as general disturbance, pollution of all kinds, or reduction of stocks of fish species on which harbour seals feed. Some possible effects of these factors on seal biology are described by Reijnders (1983). In the absence of information on large-scale human kills before the start of the bounty program in 1927, it is tempting to consider that the 1927 population was close to the carrying capacity. Extrapolation back from 1950, assuming a steady decrease between 1927 and 1950 – an assumption that could be modified by better information on bounty kills before 1950 – would give a 1927 population of approximately 70,000 animals.

Since harbour seals are very coastal animals, they seem to be more vulnerable than other species to human disturbance and the effects of pollu-

tion. For example, organochlorine compounds have been found in seals in the Wadden Sea, and this population has collapsed (Bonner, 1979; Reijnders, 1978). The present carrying capacity for harbour seals in eastern Canada south of Labrador may well be lower than it was 50 years ago. In any case, the rate of increase towards any limiting size will be slow. The kill that would maintain the population at its present level is correspondingly small. In the absence of any killing of harbour seals by humans there has presumably been some increase in abundance since 1976, which would be expected to increase the sustainable yield, but the bounty kills were clearly above the sustainable yield, perhaps by a factor of 2 or more. Taking the factor of 2 for the purposes of illustration, kills of 150 pups and perhaps 75 animals aged 1+ would maintain the population at about its current level. Any figures used as targets in a management program aimed at maintaining present abundance, whether kills represent part of a cull, bounty or other activity, would be highly tentative, and would need revision after careful monitoring of the population.

It may be noted that in the absence of any killing, the estimated rate of increase of the population of a very few percent per year is slower than that for the Pacific harbour seals, or for the more severely depleted stocks of other species of seals (see Chapter 22). If the rate of increase is correct, and not merely an estimation problem, it suggests that present population numbers may not be much below the carrying capacity.

Conclusions

The abundance of harbour seals on the Atlantic coast was reduced by bounty kills at an annual rate of approximately 4% per year until 1976, when the bounty was discontinued. The current population numbers about 13,000 animals, and is most likely increasing very slowly.

Ringed Seals

Background

The ringed seal is widely distributed throughout the Arctic, including the whole of the Canadian Arctic from northern Newfoundland to the Alaska border, including Hudson Bay and James Bay (Figure 21.9). It is probably the most abundant seal in the northern hemisphere and the second

most abundant (after the crabeater seals in the Antarctic) in the world; its total population is estimated as 6.7 million, though this figure should be interpreted with caution (Stirling and Calvert, 1979). It is generally solitary, with no marked aggregations. Large-scale movements are little known, but there are some seasonal movements associated with changes in the distribution of ice in the Beaufort Sea and off Greenland.

Figure 21.9
Canadian Distribution of Ringed Seals

Source: Mansfield (1967a).

Ringed seals are strictly arctic animals. They can remain in the Arctic year-round because of their unique ability to maintain breathing holes in ice up to two metres in thickness. Their numbers are, nonetheless, highly sensitive to annual regional variations in ice conditions, food, and predation. In the Beaufort Sea, for instance, the seal population fell by half during the severe 1974–1975 winter, which produced unusually heavy ice,

and which may have depressed the production of plankton as well. Immigration had restored the Beaufort Sea stock by 1978 (Stirling et al., 1982). Annual dispersal of young-of-the-year, often over long distances of several hundred kilometres, is necessary to maintain the overall population by replenishing coasts depleted by natural conditions or heavy predation (McLaren, 1958a; Miller et al., 1982).

Ringed seals require a stable platform for pupping in spring, preferring land-fast bay and fjord ice rough enough to collect deep snow for excavating birth lairs (McLaren, 1958a, 1962; Alliston and McLaren, 1981; Miller et al., 1982). They therefore tend to be most numerous and to produce the largest pups along complex coasts such as the shores of Baffin Bay. Ringed seals also colonize pack ice, and while pack-ice seals are more thinly scattered and produce earlier-weaned, smaller pups, they utilize a much larger habitat and may outnumber fast-ice stocks (Miller et al., 1982). Inuit have long distinguished coastal bay-ice seals (*tuvamiutaag*) from the smaller pack-ice seals (*pulajuraag*) that migrate inshore in summer (McLaren, 1958a; Miller et al., 1982). In either habitat, however, ice cover can vary yearly by a factor of two, and poor snow or an early break-up can be catastrophic.

Ringed seals are opportunistic feeders. They prefer arctic cod (*Boreogadus* and, to a lesser extent, *Arctogadus*), but they will also take advantage of summer swarms of crustaceans such as *Parathemisto* and the local availability of other prey (Finley, 1978; Lowry et al., 1980b; Lowry and Frost, 1981; Bradstreet and Finley, 1983). Arctic cod are schooling fish subject to seasonal movements, and their numbers and distribution vary considerably from year to year. Ringed seals follow arctic cod inshore in summer (Finley and Gibb, 1982) and may emigrate from coasts depleted of fish (Bradstreet and Finley, 1983), but in winter, when they cannot stray far from their breathing holes, they cannot escape local variability in food supplies (Finley, 1978). They also compete with bearded and harp seals for arctic cod and possibly some crustaceans, chiefly in summer (Lowry et al., 1980a; Lowry and Frost, 1981; Smith, 1981; Finley and Evans, 1983).

The chief predator of ringed seals is the polar bear. Bears open birth lairs and hunt seals basking or swimming along the floe edge (Stirling and Archibald, 1977; Stirling and Latour, 1978; Furnell and Oolooyuk, 1980; Smith, 1980). In the eastern Arctic, it is estimated that bears require one seal every five days (Miller et al., 1982). Although polar bears are completely omnivorous and can sustain themselves on birds and plant foliage if these foods are available (Russel, 1971), a decline in the number of seals

usually leads to a decline in the number of bears (Stirling et al., 1982). Bears tend to eat only the calorie-rich blubber of seals, leaving the carcasses for scavenging by the arctic fox and ravens (Stirling, 1974; Smith, 1980). Foxes also commonly open seals' lairs themselves, especially in the western Arctic (Smith, 1980). Ringed seals, polar bears and arctic foxes are all of considerable economic significance to Inuit and must be managed as a single interrelated system (Brakel, 1977).

Ringed seals are the most important seals in the Inuit economy, having long supplied meat for humans and dogs, skins for clothing and boats, and blubber for lamps. Some skins are traded commercially. Prior to 1962, these amounted, at a maximum, to some 20,000 skins annually, representing about half the kill (or probably, to be more accurate, half the animals recovered). After 1962, skin prices increased. Mansfield (1967a) reported that 70,000 skins were sold annually, representing most of the kill. Recent statistics for skins traded are given in Table 21.7. These statistics are for several species of seal; however, as shown in Chapter 13, nearly 90% of these skins would be from ringed seals. In recent years these skins may represent most of the seals recovered, but there is substantial loss of shot seals that sink before recovery. This loss of up to 50% of the kill is highest in the summer (see Davis et al., 1980, Table 12). The subsistence hunt has existed from time immemorial, but apart from the recent data, discussed later, there is little information on long-term trends. There has never been significant commercial European hunting.

Population Numbers

The main methods currently usable for estimating ringed seals are direct counts from ships or aircraft. Counts have been made, using dogs, of the numbers of breeding pairs in small areas, but it is difficult to cover a large area in this way. Because the seals are scattered over a huge area, counts have to be made in sample areas and extrapolated to the whole area of interest, perhaps taking into account ice conditions. A good time for aerial surveys seems to be late June, when seals bask on the ice (McLaren, 1966), but under even the most favourable conditions there are problems of seals under the water or not seen. Quite big differences exist among observations, some of which can be accounted for by such factors as the observer's position in the aircraft and speed of aircraft. Correction factors to account for seals not seen or not hauled out range from 1.2 to 2.0 (Davis et al., 1980). The most systematic surveys are probably those of Stirling et al. (1975, 1977) for the eastern Beaufort Sea, but even these have quoted confidence limits of 20%.

Allowing for possible systematic errors, the real range of likely values is greater than this figure, and the range of other estimates is even larger.

Table 21.7
Seals Sold to the Hudson's Bay Company, 1943–1984[a]

	Northwest Territories			
	Western	Central	Eastern	Quebec
1943–1952[b]	94	387	4,080	1,792
1953–1962[b]	734	867	8,501	2,519
1963–1972[b]	8,185	6,302	24,348	7,197
1973–1982[b]	4,043	2,283	23,506	2,075
1983	1,154	184	9,376	46
1984	372	23	4,084	13

Source: Hudson's Bay Company.

a. Nearly 90% of these skins would be from ringed seals.
b. Average number for the period shown.

A number of estimates have been published for different parts of the Canadian Arctic. Roughly in chronological order, these include one million for the area south and east of Lancaster Sound (McLaren, 1958a); 70,000 around the Belcher Islands in southern Hudson Bay (McLaren and Mansfield, 1960); 71,000, 36,000 and 59,000 in Home Bay, Hoare Bay and Cumberland Sound respectively, all on the east coast of Baffin Island (Smith, 1973); 455,000 and 61,000 for Hudson Bay and James Bay (Smith, 1975; though Davis et al., 1980, in re-examining the data suggest estimates of 407,000 and 56,000, and even these figures depend on a high value of 2 for the correction factor for animals under the ice); and between 67,000 and 177,000 on the fast ice and 417,000 to 787,000 on the pack ice off the east coast of Baffin Island (Finley and Renaud, 1980). Apart from this last figure pertaining to the pack-ice seals off Baffin Island, which looks high in comparison with Smith's (1973) estimate for selected areas along the east coast, the figures seem fairly consistent, at least in view of the fact that they are largely made in different places, at different times, and by different survey methods, and that no confidence limits have been attached to several of the figures.

It seems reasonable to conclude that the total Canadian population of ringed seals probably reaches seven figures, and that in smaller areas such as Cumberland Sound, there are local "stocks" numbering in the tens of thousands.

Trends in Abundance and Catches

Several of the available reports and other documents consider, implicitly and explicitly, that the abundance of the ringed seal is roughly constant. For example, the DFO (Canada, DFO, 1985) brief states, "[the population estimates] all indicate a relatively stable population of ringed seals in the Canadian Arctic since 1700–1800." The basis of this belief is not clear. One of the documents referred to in the DFO brief (Stirling and Calvert, 1979) states that "population levels are probably the same as in the 18th and 19th century, though this is not well documented." The other DFO reference on this point (Davis et al., 1980) merely mentions that "current population levels are believed to be similar to historic levels."

There are, in fact, very few records that might exist (other than references to seals' complete disappearance from old areas or appearance in new areas) that could be expected to throw light on changes in abundance since the 18th or 19th centuries. It is simply not known whether or not present population levels are similar to those of 100 or 200 or more years ago.

Similarly, it is not known whether the population abundance is now changing. Given that the precision of current census techniques is no better than ± 20%, it is unlikely that pairs of surveys would detect differences of less than 40%. That is, a decrease of 5% per year (which for a long-lived animal like ringed seal is significant) would only be likely to be detected in a pair of surveys if they took place eight years or more apart. Such long base lines do not yet exist. (The statistical argument here has been highly simplified to make the point. A more complex, and more correct statistical analysis would change the numbers slightly.)

The total kill does not seem to have remained steady. After a rapid rise to nearly 70,000 in 1964, the numbers of skins sold to the Hudson's Bay Company fell to fewer than 30,000 in 1978. The very low sales in the last two or three years (1982–1985) can be ascribed to low prices, but in the late 1970s, the prices were twice those in the 1960s. Although these sales figures are the best quantitative data available, they must be interpreted with care. They reflect hunting effort, and the proportion of skins brought in for fur, as

well as changes in availability of skins. There is also considerable variation over a period of a few years. These fluctuations are more noticeable in sales at individual settlements, and the years of peak sales are not always the same at different places. The years 1964–1965, 1969, and 1975 seem to be good ones, while sales in 1968, and 1971–1972 were poor. Such fluctuations are common in the land animals of the Arctic, though in the case of long-lived animals such as the ringed seal they presumably reflect changes in availability, or possibly changes in numbers in one or two year-classes, rather than changes in the abundance of the total population; nevertheless, Stirling et al. (1975, 1977) note fluctuations in numbers and reproductive rates in the Beaufort Sea. The fluctuations do, in any case, make it more difficult to determine the state of the population on the basis of one or two years' observations.

Sustainable Yields

Several estimates of sustainable yield (e.g., McLaren, 1962; Smith, 1973) have been made. Though details differ, the estimates are based on life tables and reproduction rates. The problem with interpreting these results is that the interpretations have to assume either a value of natural mortality or that the population is not changed. Though the calculations do show that the sustainable rates of exploitation, such as those found by Smith, are reasonable and that the 5%–10% range is consistent with the sustainable rates for other seals with similar population characteristics, there is no direct evidence that the assumptions are correct. In any case, since the observations cover a single situation, they can hardly indicate the position or value of the maximum sustainable yield (MSY) unless "we assume that the equilibrium population of southern Baffin Island is in fact experiencing maximum possible mortality" (McLaren, 1962), or make some similar assumption.

Estimation of MSY and the population abundance at which it occurs requires some knowledge or assumption about the density-dependent responses of ringed seals, or the factors controlling their abundance. Little is known about density-dependent responses, but it has been suggested (e.g., Davis et al., 1980) that the availability of stable fast ice suitable for breeding is a limiting factor controlling abundance. The younger animals are found breeding on the less stable ice, where the young are smaller and are often starved (McLaren, 1958a). If they are forced into this ice by high density in more favourable conditions, this circumstance could provide a density-dependent response. It would also suggest, to the extent that a significant

part of the population is breeding in unsuitable areas, that there is still scope for some resilience in the population. It does not, however, show whether the present population is above or below the level giving MSY, or how it compares with the limiting size of the population in the absence of any hunting.

Present Status

Considerable ignorance surrounds the present status of ringed seals. It is not known whether the population is increasing or decreasing either locally or as a whole, nor how the local or overall populations compare with the MSY or some other target level. Given the comparatively sedentary nature of the animal and the differences between hunting intensities, say, between Cumberland Sound and Home Bay (Smith 1973), great variation in status may be expected among groups of seals in different areas.

Given, too, the increase in reported catches since 1962, there are grounds for concern for at least local overexploitation. This is no new concern. Smith (1973) warns that "these developments [i.e., increased hunting efficiency] might have serious consequences in depleting the stocks in [some] areas." Davis et al. (1980) note that "there is evidence that local populations can be over-harvested", and DFO (Canada, DFO, 1985) mentions the possibility of local overexploitation.

Future Prospects

Because of the ringed seal's wide range, large total population, and relatively sedentary nature, there is no short-term cause for concern for its population as a whole, provided that there is no major change in environmental conditions. It is, however, quite possible that the catches made in some areas prior to 1983 have exceeded the sustainable yield, and the decline in sales of skins apparent in some areas in the mid-1960s might be a sign of this. If so, resumption of catching at the 1970s level might see the collapse of some of these stocks. Even if the worst effects may be reduced by increased immigration from less heavily exploited areas, and there is no increase in hunting pressure, it is possible that stringent management measures may be needed. With increasing human population in many areas (see Chapter 13), it is more likely than not that hunting pressure will increase. Management of the ringed seal harvest, backed up by adequate scientific advice on what is happening to the stocks, is therefore a matter of some urgency. It may well be that further research will show that the status of the stocks may be better

than the gloomy possibilities suggested here. However, until the range of uncertainties in population numbers and recent changes in numbers are reduced, a cautious approach is essential.

A complication that should be taken into account in managing the stock of ringed seals is the status of polar bears and arctic foxes. Both species are important predators on ringed seals, though foxes prey only on pups. Both have been heavily hunted, but hunting of polar bears is now fairly strictly controlled, and fox hunting has also declined as a result of reduced fur prices and increased costs. It is possible that an increase in polar bears or foxes could disrupt a temporary balance between seals and hunting. Likely trends in predator populations should therefore be taken into account in setting management policies for ringed seals.

Conclusions

There is a possibility, to put it no more strongly, that current catches of ringed seals in some areas are exceeding the sustainable yield, and that stocks in those areas are declining. It is also possible that even if current catches are sustainable, little or no increase in catch would be sustainable. Urgent attention should therefore be given to devising management procedures for ringed seals that are matched to the traditions and customs of the people involved. Any management should be backed by research aimed, *inter alia*, at monitoring the trends in population abundance. Apart from surveys, attention should be given to the possible derivation of indices of relative abundance from hunting records.

Bearded Seals

Background

The bearded seal is a large, solitary seal, widely distributed throughout the Arctic. In Canada the species is found from Labrador to the Alaska border (Figure 21.10). There are indications (e.g., Mansfield, 1967a) that its abundance is relatively high along the east coast of Hudson Bay and the west coast of Baffin Island, but quantitative information is sparse. Like the ringed seal, the bearded seal is believed to be relatively sedentary but it may undertake regular long-distance migrations in response to movements of ice fields (Davis et al., 1980). It is more dependent on open water than the ring-

ed seal, less often maintaining breathing holes in the ice. Its main food items are bottom invertebrates, especially molluscs, though it occasionally takes fish, particularly arctic cod.

Figure 21.10
Canadian Distribution of Bearded Seals

Source: Mansfield (1967a).

The bearded seal is hunted by Inuit. It is particularly prized for its tough and flexible skin, although this material is now largely replaced by nylon and other imported materials. The meat is also eaten by humans and dogs. The total number of bearded seals taken is not recorded. Furthermore, because many of these animals sink when shot (McLaren, 1958b), the number killed is considerably larger than the number recovered.

Population Abundance and Status

Bearded seals are even more difficult to survey than ringed seals, and few quantitative estimates of abundance are available, even from small areas. The most reliable estimates are those for the eastern Beaufort Sea, of 1,000–3,000 in 1974 and 1975 (Stirling et al., 1975, 1977). McLaren (1958b) extrapolated from the estimates of ringed seals to bearded seals on the basis of the ratio of the two species seen from survey ships. The resulting estimated figure of 185,000 for the area south and east of Lancaster Sound probably gives a useful rough guide to the numbers of bearded seals, but must be subject to even more uncertainty than the figures for the ringed seal.

Since even rough figures for the present catch are lacking, it is impossible to evaluate the status of the bearded seal population. There is also too much doubt about some important parameters of its life history (whether it breeds every year, for example, or only every two years) to permit any attempt to estimate its likely response to exploitation or the likely value of its sustainable yield as a percentage of the current abundance.

Given this uncertainty and the known fact that bearded seals have been prime targets of Inuit hunters, many of the concerns expressed for ringed seals apply also to bearded seals. There are no grounds for confidence that the stocks in areas of high hunting intensity are not being depleted. Urgent attention should be given to collecting more information about bearded seals, including estimates of the numbers killed, the numbers present, and trends in these numbers. Attention should also be given to possible management measures.

Appendix

Appendix 21.1 Calculation of Sustainable Yields

These calculations are based on equilibrium conditions, with a stable age composition corresponding to the exploitation pattern under consideration. An observed population will have a rather different age composition; for instance, one that has recently had a large kill of pups will have relatively fewer young animals so that the actual sustainable yield, that is the yield that can be maintained indefinitely, and the replacement yield, that is the yield that will leave the same population numbers, though not

necessarily the same population structure, at the end of the year (Gulland and Boerema, 1973), will be slightly different.

Pup Harvest Only

Let M_i be the natural mortality of seals at age i, let t be the age at which females, on the average, first produce a pup, and let p be the proportion of females, aged t or greater, that produce a pup in a given season. Then, if N is the number of pups born and Y is the number of pups harvested, the number of females reaching age t, assuming an equal sex ratio, will be

$$A = 0.5\,(N - Y)\exp[-\Sigma M_i],$$

where ΣM_i is the sum of the M_i up to age t.

The total number of female seals, age t or greater, will be $A / [1 - \exp(-M)]$, assuming that M_i is a constant M for $i > t$, and the number of pups born will be $pA / [1 - \exp(-M)]$, since the population is in equilibrium. Then

$$N = pA[1 - \exp(-M)] = 0.5p(N - Y)\exp(-\Sigma M_i) / [1 - \exp(-M)],$$

and on rearranging terms

$$Y/N = 1 - 2p^{-1}[1 - \exp(-M)]\exp(\Sigma M_i).$$

Harvest of Adults Only

Let F be the fishing mortality on adults. Then A, the number of seals breeding for the first time will be given by

$$A = N\exp(-\Sigma M_i).$$

The total number of adults will be $A / [1 - \exp(-F - M)]$, the number of pups produced will be

$$0.5pN\exp(-\Sigma M_i) / [1 - \exp(-F - M)], \text{ and}$$

$$Y = FA / (F + M).$$

Putting the number of pups born equal to N, since the population is in equilibrium, yields an equation that can be solved for F.

$$N = 0.5pN\exp(-\Sigma M_i)/[1-\exp(-F-M)],$$

and hence

$$F = \ln[1-0.5p\exp(-\Sigma M_i)]-M,$$

and Y/N can be calculated.

An interesting feature of these equations is that the natural mortality rates in the period before first breeding, which are hard to estimate, appear together in a summation term. This makes it possible, for the purpose of calculation, for different sets of assumptions about these maturities and the time taken to reach maturity to be lumped together in the single expression ΣM_i. The following tabulations were calculated on the basis that natural mortality in the first year of life is three times that among adults, and that among older immature animals it is 50% higher (i.e., $M_0 = 3M$ and $M_i = 1.5M$ where $0<i<t$). Thus, the sum of the natural mortality up to the age of maturity, for $t = 4$, is $(3+1.5+1.5+1.5)M = 7.5M$. The same sum would be attained for lower maturity rates and a higher t (e.g., for $t = 6$ if $M_0 = 2.5M$ and $M_i = M$ for older animals). The table below can be interpreted accordingly.

Table 21.8
Sustainable Yield Rates (as percentages of number of pups) for Different Combinations of Natural Parameters[a]

t	ΣM_i	$M = 0.08$			$M = 0.09$			$M = 0.10$			$M = 0.11$			$M = 0.12$		
		P	A	P/A	P	A	P/A	P	A	P/A	P	A	P/A	P	A	P/A
3	$6.0M$	74	47	1.6	69	42	1.6	63	36	1.7	57	31	1.8	50	26	1.9
4	$7.5M$	70	40	1.7	64	34	1.9	57	28	2.0	49	23	2.1	41	18	2.3
5	$9.0M$	66	34	1.9	59	27	2.2	50	21	2.4	40	16	2.5	29	11	2.6
6	$10.5M$	62	28	2.2	53	22	2.4	42	16	2.6	30	10	3.0	15	5	3.0
7	$12.0M$	57	23	2.5	46	16	2.9	38	10	3.3	17	5	3.4	No	No	
8	$13.5M$	52	18	2.9	38	12	3.2	22	6	3.7	4	1	4.0	No	No	
9	$15.0M$	46	14	3.3	29	8	3.6	9	2	4.5	No	No		No	No	
10	$16.5M$	39	11	3.5	19	4	4.7	No	No		No	No		No	No	

a. A - Adults; P - pups.

Table 21.8 gives the sustainable exploitation rate, expressed as the number of pups or adults, that would be taken per 100 pups born, if the population is stable and being hunted at the sustainable yield. The ratios of the numbers taken under the alternative harvesting regimes directed at taking pups only or adults only are also shown. The values have been calculated for a range of values of M (from 0.08 to 0.12), and t (from 3 to 10, or ΣM_i from $6M$ to $16.5M$), and for a reproductive rate among adults of 0.94. Table 21.9 shows the effect of different reproduction rates on sustainable yield for one set of M_i.

Table 21.9
Sustainable Yield for Different Natural Mortality and Pregnancy Rates[a]

M	$p = 0.96$	$p = 0.94$	$p = 0.90$	$p = 0.85$	$p = 0.80$
0.08	63	62	60	58	56
0.09	54	53	51	48	45
0.10	43	42	40	36	32
0.11	31	30	27	22	17
0.12	17	15	11	6	0.4

a. Age at first pregnancy is six years.

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Chapter 22

The Status of Stocks of Pacific Seals

Northern Fur Seals

The northern fur seal does not breed in Canadian waters, but does breed principally on the American Pribilof Islands in the eastern Bering Sea (Figure 22.1). Smaller numbers breed on the Russian Commander Islands in the western Bering Sea and on Robben Island and the Kurile Islands in the western Pacific Ocean. A very small group breeds on the San Miguel Islands off California.

The present population is approximately 1.2 million. At the 1984 meeting of the Standing Scientific Committee of the North Pacific Fur Seal Commission and at a 1985 meeting of representatives of Canada, the United States, the U.S.S.R. and Japan, the numbers breeding on the various island groups were estimated as follows:

Bering Sea: U.S. territory	819,000
Bering Sea and Western Pacific: U.S.S.R. territory	350,000
San Miguel Islands: U.S. territory	4,000
	1,173,000

Most fur seals belonging to the northern populations remain in the vicinity of the breeding islands between June and October, but young females and males of up to about five years, particularly those one and two years old, spread widely through the north Pacific Ocean during the late winter and spring (Kajimura, 1984). The females move as far south as about 33°N off California, but the males do not travel as far. On the eastern side of the Pacific, the southward movement seems to take place mainly within 300 kilometres of the coast, but it appears that on the return journey many of the females travel in a fairly direct line back to the Bering Sea, although some move along the coast. Most older males remain in the Bering Sea throughout the year, although it seems that some may winter in the Gulf of Alaska and on the north Pacific Ocean.

Figure 22.1
Distribution of Northern Fur Seals

Source: King (1983).

Canadian interest in the present status of the stock derives from two factors. First Canada, with the United States, the U.S.S.R. and Japan, has been a member of the North Pacific Fur Seal Commission, the international body established to regulate harvesting of the fur seal stock. Canada has therefore shared a responsibility to ensure that harvesting activities are managed in an acceptable manner. Canada has also received some direct benefit in the form of 15% of the pelts harvested. This Canadian involvement had its roots in the very active Canadian participation in the pelagic, or high seas, hunt for fur seals which took place from about 1866 until it was banned under the first international agreement in 1911.

Secondly, Canada has an interest in the northern fur seal because many of these animals pass through, and sometimes linger in, Canadian coastal waters in the course of their regular southward migrations during the winter. They feed vigorously at this time, and much of their food consists of commercially important fish, particularly herring.

Early History

The numbers of northern fur seals have undergone very large variations since the islands on which they breed were first discovered in the late 18th century. These fluctuations have, until recently, been brought about almost entirely by changes in the levels of hunting. Until the United States purchased Alaska from Russia in 1867, the hunt was under Russian jurisdiction. There was no attempt to regulate the take until 1821, when catch limits were imposed, and in some years, commercial, as distinct from subsistence, hunting was prohibited. Busch (1985) has researched the history of this hunt and estimates that from its commencement in about 1786 until the sale of Alaska in 1867, about four million fur seals were killed on the islands. The earlier uncontrolled hunting apparently reduced the population to a very low level by about 1800, but subsequent regulation of the kill, although largely on a trial and error basis, seems to have allowed the numbers to rebuild. Busch states: "By 1867 and Alaska's sale, the seal population had probably returned to nearly the pre-exploitation level of roughly three million (only four-fifths of which is . . . based on the Pribilofs)." Although there are many uncertainties in the records, Busch's estimate of a total kill of four million seals in the entire Bering Sea area between 1786 and 1867 seems reasonable.

After the United States took possession of the Pribilofs, hunting was placed on a new basis. Two companies were successively granted a monopoly

of the hunt. The first, the Alaska Commercial Company, is recorded as taking just over two million seals between 1870 and 1890. From 1890 to 1910, the North American Commercial Company held the lease, but was able to take only about 360,000 seals.

A new threat to the seal herds developed in the late 1860s. The Indians of the west coast of North America had traditionally hunted the migrating seals off their coasts for subsistence, but about 1866, other groups saw an opportunity for a commercial hunt. This hunt built up rapidly during the 1880s, and at its peak in 1892, 124 vessels are known to have engaged in it. It declined quickly as the seals became scarce, and by its end in 1910, only four vessels participated. From the California and B.C. coasts, the pelagic sealers gradually spread their operations throughout the north Pacific and into the Bering Sea. The hunt was dominated by U.S. and Canadian vessels, although some boats from other countries took part; the Japanese pelagic sealing industry was slower to develop, but later played a major role.

Because pelagic sealing operations were diffuse, it is difficult to obtain reliable data on the numbers of seals taken. Busch (1985) quotes three estimates; two for total takes of 982,000 and 1,311,000 seals, and a third for 394,000 skins landed in British Columbia from 1889 to 1910. Busch's own estimate of 1,300,000 total landings from 1870 to 1910 seems reasonable. In considering the effect on the population, however, the number of animals killed, rather than the number of skins sold, is important. For the pelagic hunt, unlike the operations on the islands, these figures are very different because of the large proportion of animals killed but not recovered. Contemporary estimates of the proportion recovered quoted by Busch range all the way from 2% or 3% to 66% (for a good hunter). Busch adopts an average recovery rate of 33% in calculating a total kill of about four million animals. This figure seems optimistic, and it appears possible that the efficiency of recovery was as low as 16%, giving a total kill of about eight million seals.

Another important effect on the seal population is the likelihood that outside the Bering Sea, the majority of animals killed were females, while on the islands the take, even in most of the early years, was probably mainly males. Furthermore, it is impossible to be sure what proportion of the seals killed by the pelagic hunt came from that part of the population breeding on the Pribilof Islands, although two factors suggest that these animals made up most of the kill. First, in recent years the animals breeding on these islands have amounted to about 70% of the total population (Fowler, 1985b). Secondly, most of the pelagic operations were based in North American ports, and although large kills were made in the western Bering Sea and off

Japan, particularly in later years, it is likely that the greater part of the catch was taken in the eastern part of the region. We may conservatively assume that at least two-thirds of the pelagic kill, or 2,500,000 to 5,000,000 animals, were taken from the Pribilof stock.

Thus between 1866 and 1910, the total kill from this stock was probably between 5,000,000 and 7,500,000 animals, an average of 120,000 to 170,000 a year. This kill reduced the population on the Pribilof Islands from between two and three million – a figure which is not far below the unexploited level (Busch, 1985; United States, 1985) – to about 300,000 (United States, 1985).

The Recent Regime

The deteriorating condition of the Pribilof seal herds between 1890 and 1910 brought the U.S. and British governments to the realization that drastic action was needed to save the populations. It would be necessary to reduce the land kill and, if possible, end the pelagic hunt. International rivalries and the entrenched position of the U.S. sealing company aborted these efforts; furthermore, efforts to stop pelagic sealing seem to have had the unwanted effect of stimulating the Japanese operations in the western Bering Sea (Busch, 1985).

Finally, in 1911, a treaty was signed among Britain (in behalf of Canada), the United States, Russia and Japan. This agreement banned pelagic sealing and gave a compensating share of the financial return from the land take to Canada and Japan. It also placed a five-year moratorium on the taking of seals except for food. The treaty lapsed in 1941, when Japan withdrew, but it was revived in modified form in 1957, when the North Pacific Fur Seal Commission was established to manage the hunt. The Fur Seal Commission was very recently terminated.

Both before and during the regime of the Fur Seal Commission, the declared objective of international management was to work towards maintaining the populations at a level of maximum productivity. The Fur Seal Commission recommended, but did not have power to set, catch levels for the United States and the Soviet Union. Its recommendations were normally based on the advice of its Standing Scientific Committee.

In accordance with the aim of allowing the population to rebuild to a productive level, kills were restricted to slow increases on the Pribilofs after the expiry of the initial moratorium; they were also restricted to immature

males, and no females or harem bulls could be taken. Under this regime the population increased steadily until about 1940, when it seems to have levelled off. From 1912 to the late 1930s, the kill was steadily increased until it passed the 60,000 mark in 1939; up to that year a total of 876,000 seals were killed, giving an annual average of 31,000. From 1939 to 1955, a further 1,038,000 seals were taken for an annual average of nearly 65,000.

In the 1950s, the concept of management for maximum sustainable yield (MSY) became widely adopted as a basis for fisheries management. This development led to the belief that the maximum production of pups would be obtained by reducing the female population substantially below the unexploited equilibrium level, although this belief was not based on any specific evidence. In an attempt to accomplish this reduction, regular harvesting of females was begun in 1956, and it continued through 1968; a total of about 320,000 females was taken, an average of 25,000 a year. Scientific advice proved incorrect, however, and the female harvest led to a drastic decline in the size of the seal population. The herd on St. Paul Island, which comprised about 80% of the Pribilof total, declined from about 1,800,000 in the early 1950s to 930,000 in 1970 (United States, 1985).

The female kill was stopped in hopes that the population would soon rebuild, since it stood at about the same level as in the early 1930s, when it grew rapidly in spite of a male harvest of about 50,000 animals a year. These hopes, too, proved unfounded, and the population has continued to show a generally downward trend despite temporary upward fluctuations in 1966 – 1967 and 1975 – 1976. This has happened in spite of a reduction in the size of the immature male harvest to about 25,000 a year. Causes of this decline will be considered later in this chapter.

Scientific Data Base

Few scientific data exist concerning the northern fur seal herds prior to 1911. Official records of the numbers of fur seals killed on the islands seem to be satisfactory (Busch, 1985), although the data on the pelagic take are much less complete. Still, the estimates of the size of the herds are extremely weak; the first experienced scientist to attempt an estimate seems to have been D. Starr Jordan, who estimated the Pribilof population at 400,000 in 1897 (Busch, 1985). Since 1911, however, when the seal hunt came under international control, an almost continuous program of data collection has been in operation. As a result, the northern fur seal is one of the best documented of all marine mammals. The major kinds of data collected have been (Smith and Polacheck, 1984):

- counts of pups born from 1911 to 1924;
- estimates of numbers of pups born from 1950 to 1985;
- estimates of harem and "idle" bulls on the islands since 1911, based first on counts and then on markings;
- counts of pups found dead from 1914 to 1922 and since 1941;
- age determinations of males harvested since 1947;
- pelagic samples of seals from 1958 to 1961.

It is not possible to make accurate counts of the total fur seal population based on direct observation, but the estimates of harem bulls and pups born provide indices which can be related fairly simply to overall population size. The data for the harem bulls are probably the more accurate, since these animals are large and conspicuous, and there are relatively few of them. The estimates of numbers of pups born in the early years when numbers were low are probably fairly accurate. Counting became more difficult later, up to 1924, when numbers were larger, but the results are considered acceptable (Fowler, 1985b). Early tagging experiments (1947–1968) encountered problems, and their results are subject to some criticism (Trites, 1984); later experiments when the animals were marked by shearing were regarded as more satisfactory.

Population Trends

Pup Production

In 1911, 70,000 pups were counted on the beaches of St. Paul Island. When regular observations ended in 1924, the count was 172,500 (Smith and Polacheck, 1984), although there is some doubt about the validity of this figure. Estimates are next available for 1940 (York, 1985a) and 1950 (Eberhardt, 1981) of 442,620 and 450,000 respectively, and the count remained close to this level until 1957. For the periods 1911–1924 and 1924–1940, the average annual rates of increase are about 7.2% and 6.1% respectively. The two estimates for 1940 and 1950 are consistent with the view that the population had reached stability by about 1940. A lower growth rate from 1924 to 1940 than from 1911 to 1924 is not unexpected.

The true rate would have slowed down as the population approached stability, and the population may have reached stability and growth stopped completely some time before 1940.

After the beginning of the female harvest in 1956, the number of pups declined quite rapidly to about 280,000 by 1962. The subsequent history of pup production could be described either as a period of approximate stability with some fluctuations until 1976 and then a fairly rapid decline, or as a continuing but erratic decline over the whole period from 1962 to the present. The average count for the years 1982–1984 has been 181,000, which is 40% of the 1950 figure. Since 1975, the average rate of decrease has been about 6% per year (Smith and Polacheck, 1984; Trites, 1984).

Mature Bulls

Since 1911, separate counts have been made on St. Paul Island of harem bulls and of "idle" bulls, which are animals of mature age (seven years or more) not occupied with harems. The numbers of harem bulls rose steadily from 1,090 in 1912 to 10,000 in 1936, a growth rate of 9.7% per year, and then remained fairly constant to 1961. The total number of mature bulls rose steadily, apart from a check between 1940 and 1950, from 1,300 in 1911 to a peak of 23,000 in 1961, an average annual rate of 5.9%.

After 1961, the number of harem bulls and the total of all bulls on St. Paul Island fell rapidly to a low of about 3,700 and 6,100 respectively in 1972. These numbers rose again for a few years to peaks of about 6,500 and 11,000 in 1978. Recently there has been a further decline, and in 1983 and 1984, about 4,800 harem bulls and a total of 9,000 bulls have been counted. The number of harem bulls thus stands at about 48% of the 1936–1962 level.

Thus the general changes in numbers of bulls have followed those of the pups, although, as is to be expected, they have lagged by several years. The sharp decline which took place following the female hunt of 1956–1968 occurred from 1957 to 1962 for pups and from 1961 to 1971 for mature bulls.

The Current Situation

Current populations on St. Paul Island, expressed in terms of pup production and of numbers of harem bulls, are about 40% and 48%, respectively, of the apparently stable levels of the 1950s. Somewhat similar

changes have taken place on St. George Island, the other major island in the Pribilof group.

Both pup production and numbers of harem bulls are declining, in spite of the fact that the kill (of immature males only) has averaged only 25,000 since 1961 as compared to 48,000 in the 1950s. Expressed as a percentage of the total number of pups born three years earlier, the kill from 1975 to 1984 represents about 10% as against 8.8% in the 1950s.

The two most important questions posed for any attempt to manage the Pribilof fur seal herd are therefore:

- How does the present population level relate to any identifiable target level at which management may be aimed?
- What causes have prevented the herd increasing to the 1950s level as it did after 1911?

Relation to Target Levels

The principles now accepted as underlying the management of marine living resources are reviewed in Chapter 27. That review explains the concept of maximum sustainable yield (MSY) and of the population level at which MSY is available. It also relates the MSY population level to other definitions of optimum or target-population levels, such as that defined under the United States *Marine Mammal Protection Act of 1972*. This section relates these general principles to the particular circumstances of the northern fur seal.

Ability to Increase

The history of the Pribilof Islands fur seals shows clearly that until about 1960, the herd had a natural ability to increase when its numbers were reduced below its unexploited stable level. The average annual rates of increase in the numbers of pups were, as was shown earlier, about 7.2% and 6.1% in the periods from 1911 to 1924 and from 1924 to 1940 respectively. Since no females were harvested, these figures represent the total rate of increase in the population. Chapman (1981) fitted a regression line to the pup counts from 1912 to 1924 and obtained a rate of increase of 8.2%.

A crude calculation can be made of the natural rate of increase in operation over the period when the population declined from an unexploited level in 1868 to the depleted level in 1910. If the range of likely values of the initial population was two to three million, and the depleted population was 300,000 while the total catch was five million, the average natural rate of increase was about 5%–9%. However, if the total catch was 7.5 million, the rate of increase was 10%–15%. These figures are more or less consistent with the more reliable values for the later years. This method calculates the average rate of natural increase from initial and final population size and total catch. (See Appendix 22.1.)

Density Dependence

If a population is able to achieve a natural rate of increase in response to a reduction in its numbers, some factors affecting the natural recruitment and/or the mortality rates must behave in a density-dependent manner.

Fowler (1986) examined the extent to which density dependence occurs in a number of characteristics of the northern fur seal. He found positive evidence of this effect in:

- survival of pups prior to leaving land;
- survival of males up to two to three years of age (comparable data are not available for females);
- age at reproductive maturity;
- growth rate as measured by a number of factors, including pup weight at two months, length and weight of males and females collected both on land and at sea, and tooth weight.

Concerning density-dependent growth and age at maturity, Fowler notes:

> *It is well-known that among many animal species it is often easier to predict the timing of first reproduction . . . on the basis of size than on the basis of age.*

MSY Level Relative to Unexploited Level

For Overall Harvest

Direct determination of the population level (relative to the unexploited level) at which the sustainable yield is a maximum (the MSY level) would require masses of accurate data on the rate of increase at various population levels. These data are not now available for fur seals, nor are they likely to be available in the foreseeable future. Indirect approaches to determining the MSY level are, however, possible. It is now generally accepted that for large mammals, the MSY level is above, and sometimes well above, 50% of the unexploited equilibrium level.

Fowler (1984b) states that the MSY level for the northern fur seal is 0.6 of the unexploited level. This figure is based largely on a general study conducted by Smith (1973) and on an analysis made by Eberhardt (1981) of the relation between northern fur seals' survival to three years of age and the numbers of pups born. Examination of Eberhardt's analysis, however, reveals several problems. First, as Eberhardt points out, while the data lead to a definite conclusion that the female pup level giving maximum net recruitment on St. Paul Island is fairly close to 200,000, they give little indication of the number of pups at the unexploited equilibrium. Secondly, in the data series used, all the points for numbers of female pups between 100,000 and 200,000 were for years between 1958 and 1965; as will appear later, it is likely that in this period extraneous factors were reducing the rate of survival to three years of age. Compensation for this effect would tend to reduce the estimate of the relative MSY level. Thirdly, Eberhardt's analysis deals only with the effect of density-dependent changes in the rate of survival to age three; as will be seen later, there is evidence that other factors may contribute to density-dependent changes in net rate of increase. There are no quantitative data on these effects.

Fowler (1984b) also shows that for a wide range of animals there is a fairly linear relationship between the maximum net recruitment level and the logarithm of the maximum rate of increase per generation time. Applying this relationship to a maximum rate per generation time of 0.88 (derived from Smith, 1973; Eberhardt, 1981) gives an MSY level for the fur seal in about the range of 0.55–0.75.

Fowler notes that most of the density-dependent relations he examined are non-linear, with the most rapid change in the parameter occurring

not far below the maximum population level. Again, this finding is consistent with the maximum net recruitment occurring at a population above 50% of the unexploited level.

It seems likely that the MSY population level for fur seals is between 50% and 100% of the unexploited equilibrium level. The precise level may best be described by a statement of an expert working group which considered this problem in 1979 in relation to tropical Pacific porpoises.

> *Opinion within the group is that the MNPL (maximum net productivity level) is likely to be in the range of 65 to 80% of the equilibrium unharvested population level (carrying capacity or largest supportable population). In the absence of better information, all levels within this range were treated as being equally likely; the midpoint (72.5%) cannot be regarded as "the most likely value" (Smith, 1979, p. 6).*

For Male Harvest

The population level giving maximum natural increase is not, however, a good indicator of the level giving maximum yield unless harvesting is spread evenly over the population at, and above, the age to which recruitment is measured. While many marine animals, including fish and baleen whales, meet this condition, the fur seal does not because harvesting is almost entirely confined to males of two to four years. A close parallel is provided by the sperm whale, which also breeds through harems, and for which harvesting in many of the major fisheries has been largely restricted to males. The principles underlying the identification of population level and structure in the sperm whale have been extensively studied (e.g., Allen, 1980, p. 84) and are essentially applicable to the northern fur seal. For both these animals it is necessary to consider the females and the males separately.

The aim of management is now to achieve the maximum number of males of harvestable age in excess of those required to fertilize the females. To produce this number, the number of mature females should be quite close to that which exists in an unexploited population, but the number of males will be much smaller. These guidelines imply a continuation of the present policy of a minimal female kill. The precise level for males depends on the

values of the various vital parameters such as harem size, number of mature males and pregnancy rate, and the way they change with population size; in particular:

- the most desirable harem size;
- any need to have a reserve of mature males to replace periodically those holding the harems;
- the effect on female pregnancy if the ratio of the number of mature males to the number of harems drops below the optimum.

For sperm whales, most combinations of likely values for the various parameters lead to MSY population levels of about 85%–95% of the unexploited level for females and 35%–50% for males.

No detailed data seem to have been published on harem size in northern fur seals. Taking the number of pups as a minimal estimate of the number of breeding females, the published counts of pups and of harem bulls lead to estimates of the average harem size in a year as generally ranging between 25 and 60 animals, and most commonly between 35 and 45. However, Fowler (1985c) advises that the current view among biologists is that the natural harem size of northern fur seals is between 12 and 15 adult females per breeding territory-holding male. No significant variations in harem size over time have been identified.

The population levels supporting a maximum continuing yield cannot be identified from the available data. Under conditions existing up to 1958, the population levels between 1936 and 1958 were capable of sustaining a high level of pup production. From 1940 to 1957, the number of pups produced on St. Paul Island remained fairly constant at about 450,000 a year, and few females were being killed. The number of harem bulls also remained fairly constant during this period. It is reasonable to consider these population levels as close to the maximum productivity levels for harvesting three- and four-year-old bulls under the environmental conditions that existed at that time. Since the number of idle bulls (and therefore the total number of bulls of mature age) continued to increase at least until 1957, pups could probably have been maintained at 1940–1957 levels, with a slightly larger kill of young males, at least during the latter part of this period.

In the absence of any real data pertaining to the original size of the unexploited fur seal populations, it seems best to take the 1940–1957 popula-

tion levels on the Pribilof Islands as a lower bound of the maximum production level of an unexploited fur seal population.

Relation to Optimum

Chapter 27 shows that while the population levels corresponding to maximum sustainable yield or maximum net recruitment (MNR) may be defined at least conceptually, the optimum population level may lie within a wide range, depending on the combination of factors it is desired to optimize. Definitions under the United States *Marine Mammal Protection Act of 1972* place the optimum population level in the range between the maximum net recruitment level and the unexploited level. Recognition of the intrinsic value of living seals also places the optimum population level above the MSY or MNR level, as does economic optimization of any harvesting process, provided that costs for a given harvest decrease as the population increases. On the other hand, if social or economic costs related to the abundance of seals are taken into account, such as damage to gear or removal of parasites from fish, the optimum population figure is moved downwards relative to the MSY or MNR level.

As long as management of the northern fur seal remained within the ambit of the North Pacific Fur Seal Commission, its aim was defined as that of maintaining the population at levels "which will provide the greatest harvest year after year". This is a definition which approximates quite closely to the MSY level.

Costs to Canada from the presence of fur seals are treated in Chapter 29. They appear to be minor, and the method of harvesting involves no direct cost to Canada. Thus, as long as Canada is primarily interested in the fur seal as a harvestable resource, the optimum population level of fur seals will be about the MSY level or, preferably, somewhat higher to allow for risks of error and to take account of intrinsic values.

Present Levels

The population figures of pups and harem bulls now stand at about 40% and 50%, respectively, of 1940–1957 levels and are continuing to decline. If the environment remains unchanged, these figures would indicate that the population is now well below the optimum level, however defined, and that management policies should be adjusted accordingly. There is evidence, however, that the current situation is the result of a new

source of mortality. If this is so, it is impracticable to try to define what the optimum population levels would be if the new conditions persist. The appropriate strategy appears to be to try to stabilize the situation while accumulating additional knowledge, rather than to move the population towards any predefined level.

Possible Causes of Failure to Rebuild

Food Supply

When it became evident that the fur seal population was not rebuilding as expected after the end of the female kill in 1968, suspicion was directed towards a possible reduction in food supply resulting from the large commercial fishery which had developed in the Bering Sea. It now seems likely that this was not the cause. Some density-dependent vital parameters, believed to operate through the availability of food, now stand at values similar to those prevailing in the 1920s, when the fur seal population was about the same size as it is at present (Fowler, 1985b). These parameters include the weight of pups at birth, the survival rate of pups on land, measures of growth such as the length and weight of harvested males, and the weight of their teeth.

This view is supported by more direct evidence concerning the quantities of food available to the fur seals. The fur seal, like most seals, is an opportunistic feeder, taking a wide variety of species of fish and squid according to what is available to it. Thus it can compensate for scarcity of one food source by changing to another, more readily available form. It is recorded as feeding on fish of 17 families in the Bering Sea, and in its southern migrations its principal prey changes from area to area as it travels along the coast (Kajimura, 1984). In addition, there is little evidence of any significant current shortage of the principal prey species as a result of the Bering Sea fishery. The fur seal's most important prey in the Bering Sea are capelin, walleye pollock, Pacific herring, Atka mackerel and two or three species of squid. Of these, the capelin has not been fished in these waters, the Pacific herring fishery is of minor importance, and the squid and mackerel fisheries began in the eastern Bering Sea in 1977 and 1978, and are still fairly small.

The walleye pollock is the most important species as it is both much the most abundant commercial species in the Bering Sea and a major food of fur seals, especially in the vicinity of the Pribilof Islands. Pollock were subject to a very heavy fishery in the early 1970s and, according to Kajimura

(1984), suffered a decline in abundance which was arrested when the United States placed restrictions on foreign fishing. Since that time the biomass has remained fairly stable (Bakkala et al., 1984). The biomass of pollock, however, appears to have been lower since about 1970 than it was during the preceding 30 years, when the fur seal population reached stability at a high level. It is not known whether the more abundant fur seal population of that time affected the size of the pollock stock. Although it seems unlikely that shortage of food has contributed seriously to the failure of the fur seals to rebuild their numbers since 1968, further examination is needed of the relation between the seal population and the pollock stock.

Exploitation

The average number of male fur seals killed on St. Paul Island during the last seven years is 24,500, less than half that taken between 1931 and 1935 (52,800 annually), when the population was about the same size and growing rapidly. Data are not available to support a comparison of the number killed with the number of pups born between 1931 and 1935, but the number killed in the 1950s, when the population was apparently stable, represented about 9% of the pups born three years earlier, compared to 10% of those born from 1975 to 1984. These figures do not suggest that the population is currently overexploited as compared with the past.

Of course, the regular kill of a substantial number of animals must affect the size and composition of the population, but it seems that some new factor is causing the population to stabilize at a lower level or to decline under a harvesting regime which previously allowed an increase in a population of similar size. This view is supported by the fact that the smaller fur seal population on St. George Island, where no killing has taken place since 1972, is also decreasing. There is some argument as to whether the proportional rate of decrease is as great on St. George Island as on St. Paul Island, since the results of statistical comparisons depend on which series of years is examined. Nevertheless, some decrease is taking place on St. George Island.

The suggestion merits consideration that cessation or reduction of the male harvest would increase the proportion of males to females, and that this change might bring about an increase in pup mortality on land. If it is true, "termination of the harvest could impede a recovery of the population to higher levels" (United States, 1983). Swartzman (1984) has examined statistical data bearing on this problem. The results are conflicting: for St. Paul Island, multiple regression shows that pup mortality is positively corre-

lated both to pup production and to the ratio of adult males to females, although pup production is a much higher contributor; on St. George Island, only pup production shows a significant correlation to mortality. Concerning the Russian sites, neither variable shows correlation on Robben Island, while on the Commander Islands both variables are significantly correlated, the larger contribution being made by the sex ratio. While further work might show a real relationship, the effect is likely to be small, and it is unlikely that discontinuance of the male harvest would materially slow any build-up of the fur seal population.

Loss of Breeding Beaches

Trites (1985) has pointed out that the limited size of the breeding beaches may restrict the size of the fur seal populations and cause density-dependent effects. If the beaches are overcrowded, adults may bite and trample young pups, causing increased mortality. These circumstances may provide a mechanism for the density-dependent effect on pup mortality noted by Fowler (1986). It has been suggested that one effect of the female kill from 1956 to 1968 was to denude some of the beaches of their breeding populations, and because females tend to return to the beaches where they were themselves born, reoccupation may have been slow to take place. Such a process could slow down or prevent population recovery after the female kill. Two factors indicate, however, that the loss of breeding beaches is not the primary cause of the present situation: first, while this occurrence could slow down recovery, it would not produce the further decline which is now taking place; secondly, the survival rate of the pups in the first few weeks is now high and not at the low level which would be expected if the beaches in use were overcrowded.

Juvenile Mortality

Although none of the preceding possibilities seems likely to account for the current decline in the numbers of fur seals, there is good evidence about the stage in the life of the seals at which the critical change has taken place. Since about 1970, there has been a decrease in the survival rate of the young males. Since the females do not return to the islands while immature as the males do, they cannot be counted at this age, and comparable estimates of mortality rates are not available. There are theoretical grounds for thinking that a similar change has taken place for females. There are indications (Lander and Kajimura, 1982; Eberhardt, 1981) that prior to the

female kill, the male juvenile survival rate was to some degree density dependent. Since 1968, however, the survival rate has not increased as the population diminished, but has remained at a level substantially lower than that of most years since 1950 (Trites, 1985; Fowler, 1985a).

While there is some discussion concerning the way in which these survival rates should be calculated (e.g., Eberhardt, 1981; Trites, 1985), the differences between the rates calculated in different ways are not significant in their effect on the overall population trend. Trites (1985) has assumed that young males and females have the same survival rates. He has used a simulation to show that a combination of the known catches, including those of females from 1957 to 1968, and the estimated year-to-year survival rates to age two will account quite closely for the decline in the number of pups since 1957, and for the failure of the numbers to recover in recent years. If it is assumed that the survival rates of the older males were higher in the 1950s than in the following two decades, the results also follow closely the changes in the total numbers of mature bulls.

Predators

The question then arises of the cause of increased mortality rates of juvenile animals in recent years. No evidence suggests any increase in disease or parasitization which could produce increased mortality rates for young fur seals. Possible predators on juveniles in the Bering Sea are killer whales and Steller sea lions. It is not known whether the numbers of killer whales are changing. There do not seem to be any indications of a significant increase in the numbers of Steller sea lions anywhere within the eastern range of the northern fur seal. A marked decline is, in fact, occurring in the numbers of Steller sea lions in part of the Aleutian chain (Braham et al., 1980; Loughlin, 1984). On the coast of British Columbia, the numbers of Steller sea lions breeding on the rookeries have not recovered as expected after the discontinuance of hunting in 1964. However, there has been an increase in the numbers of these animals breeding on the adjacent Alaskan coast, and the total numbers feeding in the region may have increased somewhat, although they are still well below the 1956 level. Recent changes in the numbers of Steller sea lions are discussed later in this chapter.

Abiotic Factors

Abiotic factors, such as changes in oceanic circulation patterns and associated variations in local temperatures and salinities, could influence

the abundance of fur seals in a number of ways. Such relationships can be difficult to identify and still more difficult to explain. Up to now, no strong relationships have been found. Roppel et al. (1963) and Vladimirov (1974) quoted by Trites (1985) found statistically significant correlations between pup survival on land and weather conditions on St. Paul Island and on Robben Island. However, more detailed studies made by Trites (1985) on St. Paul Island over a longer period did not confirm such a relationship. Trites compared the physiological needs of the pups and the annual weather pattern on the island to show that the fur seal is well adapted to conditions in the area. The annual weather cycle provides the right conditions at exactly the time of year when the pups are ashore. York (1985b) demonstrated a small, but statistically significant, correlation between the harvest rate of fur seal cohorts on St. Paul Island (itself dependent largely on the survival rate of fur seals to ages three and four) and the mean temperature over the previous four years at Pine Island on the B.C. coast. A variety of explanations of such an effect could be postulated but as York has said, "it suggests that the survival of young fur seals may be partially regulated by oceanic conditions in the north Pacific Ocean." These results emphasize the need for further studies to determine the nature and degree of environmental factors in long-term fluctuations in the abundance of fur seals. There is no evidence now to link the apparent declining trend in the population in recent years with any environmental effect.

Entanglement

Seals, like many other marine animals, are exposed to the risk of becoming entangled and killed in fishing gear which is now widely spread throughout the oceans. This risk is from gear which is in working order and actively fishing, and from fragments of broken and discarded gear which are adrift. The question of the incidental capture of seals in the process of fishing operations is discussed in Chapter 23. The main source of this kind of mortality among northern fur seals is the Japanese drift-net fishery for salmon in the north Pacific Ocean. The problem seems, however, to be a fairly minor one, since only a few thousand seals are killed in this way each year.

Entanglement in fragmented and discarded gear and in plastic debris from other sources appears to be a much more serious problem. It affects fur seals, other seals, whales, dugongs, turtles and seabirds. (See Chapter 23.) The effects on fur seals have been reviewed extensively by Fowler (1982, 1984a, 1985a). They were first observed in relation to northern fur seals in 1936. However, in the 1960s, when the use of plastic in

fishing nets and packing materials became common and the large groundfish fishery in the Bering Sea developed, entanglement began to occur on a significant scale. Since about 1970, some 0.4% of the returning harvestable male fur seals have been entangled in pieces of plastic.

Fowler has reviewed evidence relating to entanglement and has concluded that a significant proportion of young males die from this cause after leaving the breeding islands and before returning as two- or three-year-olds. Evidence supporting this conclusion includes the following:

- There is a relatively low ratio of large to small pieces of netting on returning seals, compared to the ratio in netting washing up on beaches; it is therefore assumed that animals entangled in small pieces generally survive, while those entangled in large pieces die.

- A similar comparison applies to the relative amounts of netting of all kinds and of packing bands on seals and on beaches, suggesting that netting pieces are more destructive to seals than packing bands.

- Originally the survival rate of young males from the time of departure from the islands till their return showed a good correlation with the survival rate of the same pups prior to departure. Recently, the survival rate at sea has been less than that expected from this correlation, and the extent of the deficiency has a positive correlation with the proportion of the same animals that were entangled in netting on their return.

- The annual rates at which the numbers of pups and the numbers of harem bulls have been declining in recent years show positive correlations with the entanglement rate at the appropriate number of years earlier.

- The proportion of returning three-year-old males entangled is only 54% of the proportion of two-year-olds entangled. This circumstance suggests that excess mortality of entangled animals has occurred in the interval.

Fowler (1985a) has pointed out that the use of these relationships to estimate the extent of mortality caused by entanglement involves several assumptions which have not yet been fully tested. These assumptions relate, for example, to the size composition of the debris in which seals become entangled, the mortality rate of animals entangled in small pieces of debris, and the extent to which females become entangled. Nevertheless, it is clear that entanglement has increased in recent years, and that it does contribute

to the deaths of juvenile fur seals; no other cause of additional mortality since about 1970 has been identified. The relation found by Fowler (1985a) between the departure of the survival rate from the value expected from the regression on survival on land and the entanglement rate forecasts a decrease of 0.15 in the survival rate to first return at age two or three for the average current entanglement rate of 0.4%. The other indicators of the effect of entanglement on survival suggest values not inconsistent with this figure. Such a decline in juvenile survival would apparently be sufficient to cause the observed decline in pup production. It is therefore reasonable to consider, at present, that entanglement is probably a major contributor to the post-1970 failure of the fur seal population to rebuild. Entanglement is not necessarily the only factor responsible for this problem, and further studies to identify other possible factors are needed. Such studies should examine both abiotic factors, such as climatic changes and pollution, and biotic factors, including food supply, predation and disease.

The general question of the threat posed by plastic debris to a wide variety of marine vertebrates is reviewed briefly in Chapter 23. Other kinds of seals, including Steller sea lions (Calkins, 1984) and monk seals (Henderson, 1984), become entangled, but the phenomenon has been most fully studied in the case of the northern fur seal, and it seems likely that this species is one of those most seriously affected. Japanese experiments with fur seals in tanks (Yoshida and Baba, 1984; North Pacific Fur Seal Commission, 1984, p. 39) confirmed the tendency for the animals to become entangled in pieces of netting placed in the water. Entanglement resulted when seals charged into the netting at high speed and when young animals played with it. Females as well as males became entangled. This observation is important, since all the data on entanglement in the wild population refer to males.

If entanglement in plastic debris does emerge as the principal cause of the failure of the fur seals to recover their population levels, there may be some chance of alleviation of the situation in the long term; this might come about, for example, through changes in technology or as the result of a deliberate effort to reduce the amount of plastic debris in the ocean. Signs already exist that the amount of plastic debris may be decreasing; Merrell (1984) records a 37% reduction, between 1974 and 1982, in the amount of trawl web coming ashore on Amchitka Island in the Aleutians, an area which is well within the normal range of the Pribilof fur seals. The proportion of entangled returning fur seals rose rapidly from 1967 to reach a peak in 1975, but fell again in the next two years and seems to have been fairly constant since 1978 (Fowler, 1985a).

Awareness of the damage caused by plastic marine debris to seals, other marine mammals, other vertebrates and especially to seabirds, is growing rapidly. It has led to pressure in the United States for action to reduce the amount of such material in the ocean (Wallace, 1984), and pressure of this sort seems likely to spread. The fishing industry is the principal source of the problem and could act to improve the situation. The simplest and most important step would be to reduce the throwing overboard of plastic debris of all kinds, but particularly of netting fragments, damaged nets, plastic wrapping bands and ropes. Probably an equally valuable measure would be to retain on board material of this kind brought up in nets. Organized work to clean up material washed up on beaches has already been started in some places, and its extension would be valuable. A vigorous program of public education and of appropriate regulatory measures will probably be required to bring about any substantial and continuing improvement. In the long term, it may be practicable to introduce technological changes towards the use of biodegradable materials in certain parts of fishing gear such as hanging twines. (See Chapter 23.)

International Management

As was noted earlier in this chapter, management of the northern fur seal was placed on an international basis with the signing of the Fur Seal Treaty of 1911 between Great Britain (in behalf of Canada), the United States, Russia and Japan. The Fur Seal Treaty lasted from 1911 to 1941, when it was abrogated by Japan. From 1941 to 1957, the Pribilof herd was protected under a provisional agreement between Canada and the United States.

The Interim Convention on Conservation of North Pacific Fur Seals, which came into force in 1957, was signed by Canada, Japan, the United States and the U.S.S.R. It was extended by protocols which took effect in 1964, 1969, 1976, and 1980. It was this Convention that established the North Pacific Fur Seal Commission. A 1984 protocol was to have extended the Convention until 1988. A statement attached to it included:

- recognition of the need for further research on the entanglement problem;
- agreement to take all appropriate measures to halt the discarding of net and gear at sea, in accordance with the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention);

- provision for action in unforeseen circumstances;
- agreement to review the Convention within two years to determine if modifications or renegotiation are necessary.

However, the protocol was not ratified by the United States. The Convention expired in October 1984, and the North Pacific Fur Seal Commission has been terminated.

In 1985, interim measures in the United States placed harvesting on the Pribilof Islands under the control of the local people, but limited the harvest to between 3,000 and 15,000 animals to be taken for subsistence purposes only (Associated Press, 1985).

Policy Options

In the short term, management of fur seals will be the responsibility of the individual countries within their 200-mile limits. It is to be hoped that there will be some international sharing of information to assist in each country's management efforts.

In the longer term it may be advantageous to include the fur seals in the scope of a broader treaty for the management of the marine living resources of the north Pacific Ocean and the Bering Sea. Negotiation of any international fur seal or broader convention will likely include consideration of three of the points covered by the 1984 protocol: research on entanglement, efforts to stop discard of plastic debris, and provision for action in unforeseen circumstances.

If any new arrangements are negotiated for the international management of fur seals in the north Pacific, the objectives at which management should be aimed will require careful consideration. The previous Convention stated its goal to be:

> *. . . to take effective measures towards achieving the maximum sustainable productivity of the fur seal resources of the north Pacific Ocean so that the fur seal populations can be brought to and maintained at levels which will provide the greatest harvest year after year, with due regard to the productivity of other living marine resources of the areas.*

This statement, which clearly recognizes the harvest as the main objective of the Convention is now unacceptable to many animal-protection organizations. These organizations would certainly take the opportunity to press the case for terminating the hunt. The above definition of the target population is also incompatible with the definition of optimum population level under the United States *Marine Mammal Protection Act of 1972*. Pressure has already been brought to bear on the U.S. government to make management of fur seals compatible with the Act. It is impossible to predict the positions that governments will take in discussions relating to the future management of fur seals, but it is obvious that the above issues will be considered.

Canada's Relation to the Commission

Canada (represented by Great Britain) was an essential member of the Fur Seal Commission as originally established because of its active involvement in the pelagic hunt. The material benefit which Canada has gained from the Commission was 15% of the sealskin take, which it receives in compensation for refraining from hunting seals on the high seas. Financially, this benefit has been quite small, even before the collapse of the sealskin market; the average net revenue for the years 1976–1982 was about $300,000.

The only other effect of fur seals on the Canadian economy seems to be through the damage done by the seals to the west coast fishing industry, discussed in Chapters 24 and 25. Fur seal damage seems to be relatively small compared to that caused by the sea lions and harbour seals in the same area.

Whether Canada is currently in receipt of any direct economic effect from the fur seals or not, the seals exist as a potentially exploitable resource in which Canada has identifiable interests. These interests stem both from the fact that a substantial part of the population spends a vital, although fairly short, period in Canadian waters and from Canada's traditional participation in the seal fishery.

Regardless of economic benefits, the northern fur seals constitute one of the great marine mammal populations of the world. The waters they inhabit are generally within Canada's area of interest and, seasonally, a significant part of their population lives within the Canadian fishing zone.

For all these reasons it is appropriate for Canada to take an active part in any international management of the fur seal populations. Canada's

efforts should be directed towards replacing the North Pacific Fur Seal Commission by some international arrangement which will provide effective management.

Benefits of the Commission

The primary benefits derived from the Fur Seal Commission were that it provided a mechanism for regulating the exploitation of the fur seals which has proved very effective in the past; it also stimulated a large and well-coordinated research program. Since the Commission has been disbanded, it seems possible that funding for the large U.S. research program and for the smaller but valuable Canadian program could be cut back or even terminated. The Royal Commission believes that support for the Canadian research program should be maintained at the present level.

The Commission's presence was particularly important because it prohibited pelagic hunting of fur seals, apart from a strictly limited take for research purposes. With the Convention lapsing, pelagic hunting could possibly be resumed, perhaps by a country that was not a member of the recent Convention. Such a development could pose a very serious danger to the seal herds. The take might be uncontrolled, and the kill would be impossible to measure even if landing statistics were kept, since the recovery rate could not be checked. Furthermore, a large proportion of the kill, particularly if taken outside the Bering Sea, would be likely to be females, and history has already shown the catastrophic effect of such a kill. Canada will maintain a ban on pelagic sealing (Goodman, 1986).

The Royal Commission believes that it is also important for the statements attached to the 1984 protocol, relating to research on entanglement and the prevention of the dumping of plastic material, to receive the strongest possible support in any future national or international management efforts.

The Objectives of Management

As long as Canada's interest in the fur seals is based primarily on these animals as a resource, it is appropriate to define a target level for management as somewhat above the MSY level. Under present conditions, however, it is impossible to define this level in numerical terms. In these circumstances it might be appropriate for any new management guidelines

to include the principle that no harvest should be taken which would cause the net productivity of the fur seal population to decrease.

Inclusion of Fur Seals in a More General Agreement

There would be advantages in bringing the management of fur seals into the ambit of an international body having general responsibilities for the marine living resources of the Bering Sea and north Pacific Ocean. These advantages include better provision for examination of the relation between the seals and the rest of the marine ecosystem, particularly other exploitable resources, and a wider scientific contribution to discussion of seal-management problems. These benefits are presented in more detail in Chapter 28 of this Report. The possibility of establishing a more general body for this region has been under discussion for many years. The Royal Commission suggests that the Canadian government take steps to promote this proposal and to ensure that fur seals are brought within the purview of such a body if it is established. Nevertheless, in the light of past experience, the Royal Commission is not confident that such an international agreement will be achieved within the next few years. The Royal Commission therefore considers that Canada should actively support any moves to establish a special international arrangement for the management of fur seals in the north Pacific.

Conclusions

1. There can be no doubt that the Pribilof Islands fur seal herd is far below its original unexploited level – probably, indeed, standing at less than 50% of that level – and that it has been decreasing over the last decade both where males are harvested (on St. Paul Island) and where they are not harvested (on St. George Island). It is likely, but not certain, that the decline is continuing at the present time.

2. In the 1950s, the population was apparently stable with a high level of yield. It may have been close to the MSY level, since no females had been harvested for many years. Thus the restoration of the 1950s level would appear at first sight to be an appropriate target, whether the objective is to achieve a high continuing yield or to bring the population to some less definite optimum level, such as that defined under the United States *Marine Mammal Protection Act of 1972*. It is not clear, however, whether under present conditions, the population could rebuild to this level even if it were fully protected.

3. The only hypothesis relating to the cause of the recent decline that is supported by much evidence is that the decline results from an increase in the mortality rate of young animals, probably over their first two to three years after they go to sea.

4. The weight of the evidence suggests that the harvesting of immature males at current levels is not contributing to the decline in population, measured either in terms of pups born or in terms of numbers of mature bulls. It follows that discontinuance of hunting would not facilitate or accelerate the population-rebuilding process. Nor is discontinuance likely to slow down population recovery to any material extent.

5. Since the increase in juvenile mortality rate appears to be the result of extraneous causes, a reduction in that mortality rate could occur only from a modification of these causes. If the major cause lies in the natural environment – in climatic changes, for example – human intervention is not practicable, and there is little to do but hope for a beneficial natural change in the future and adopt a cautious approach to measures which might affect the recovery of the population. However, no significant relationship with any climatic factor has yet been identified.

6. There is quite persuasive evidence to support the hypothesis that the principal, but not necessarily the only, cause of the increased mortality rate of young fur seals is their entanglement in lost or discarded netting and other plastic debris. Such debris increased rapidly with the introduction of synthetic netting materials, and the proportion of seals entangled rose sharply in the mid-1970s. It has apparently stabilized in the last few years, and it is to be hoped that no further increase will occur. Conservation of fur seals, and probably of other pinnipeds, is one of many reasons to support any measures which can be taken to reduce the amount of plastic debris adrift in the oceans.

7. It is desirable that Canada work at an international level to ensure that, as quickly as possible, the Interim Convention on the Conservation of the North Pacific Fur Seals is replaced by some international arrangement to provide effective management of fur seals. Such a body is necessary to maintain the existing effective regulatory and research programs. It is particularly needed to ensure that pelagic hunting of fur seals is not resumed, since such a development could well have a disastrous effect on the fur seal populations. In the longer

term it may be useful to bring the fur seals within the ambit of any international body which may be established to exercise responsibility for the marine living resources of the north Pacific Ocean and Bering Sea as a whole.

8. In any future negotiations concerning fur seal management it will be important to provide for a commitment to expanded research on the entanglement problem and to the adoption of adequate measures to prevent the discarding at sea of netting and other plastic debris.

9. The Royal Commission considers that the objective of management of the seal herds that was defined in the preamble of the Convention is compatible with the present policy of the Canadian government and with the views of this Commission concerning the use of seals as a resource for the benefit of humankind, provided that this management is carried out with the minimum of cruelty and without endangering the survival of the fur seal populations.

10. In any future fur seal management objectives, the target level of the population should be defined not as the maximum productivity level, but as a figure somewhat above this level.

    In order to provide guidance under present conditions, in which the maximum productivity level cannot be identified in numerical terms, a provision should be incorporated to the effect that no harvest be taken which would cause the net productivity of the fur seal population to decrease.

11. There would be advantages in the establishment of an international body with general responsibilities for the living resources of the Bering Sea and north Pacific Ocean. The Canadian government should take appropriate steps to support the establishment of such a body.

Sea Lions

The ranges of the two species of sea lions which inhabit the north Pacific Ocean overlap on the B.C. coast. The Steller sea lion is a northern species most abundant in Alaskan waters, and the California sea lion is most numerous off California and Mexico. Both species are common on the B.C.

coast, but only the Steller sea lion is resident. The California sea lion visits in winter when the males, but not the females, migrate north from their breeding grounds. Until about 1970, the California sea lion had been almost unknown on the Canadian coast, but since then the number of visitors has increased substantially.

For most of the information relating to the history and present status of both species on the B.C. coast, the Royal Commission is indebted to Dr. M.A. Bigg of the Department of Fisheries and Oceans Pacific Biological Station. Bigg's (1985a) study is based on the results of regular aerial surveys of the sea lion population carried out from 1971 to 1984, and on the collection and analysis of all available data on numbers of sea lions seen, and on numbers killed, from 1892 to 1984, by different individuals and organizations (Bigg, 1984). Counts of sea lions on the B.C. coast up to 1956 were previously reviewed by Pike and Maxwell (1958).

Steller Sea Lions

The range of the Steller sea lion extends over the coasts of the north Pacific, from California in the east into the Bering Sea and to the Okhotsk Sea and the Kurile Islands in the west (Figure 22.2). Loughlin et al. (1984) reviewed the available data on the size and distribution of the population. In total there are about 230,000 animals; about 25,000 are found on the Asiatic coast, about 100,000 in the Aleutian Islands and the Bering Sea, a further 100,000 in the Gulf of Alaska and southeast Alaska, and the remainder between British Columbia and California. The Canadian population makes up less than 5% of the total.

Data Base

Counting of Steller sea lions is simplified by the fact that this species comes ashore in numbers at only a few regular sites. The most important sites are the rookeries where all the breeding takes place. The population on the rookeries is at a maximum during June and July, when virtually all the births occur. Then the animals, including the pups, gradually disperse. Only a few remain in the winter. Nine rookeries on the B.C. coast are known to have been occupied for some period.

Figure 22.2
Distribution of Steller Sea Lions

Source: King (1983).

Bigg (1985a) distinguishes two other categories of hauling-out sites: year-round non-breeding sites, of which 12 were identified, and 28 sites occupied only during the winter. Attempts to estimate the sea lion population by direct counting must allow for the movements of animals among the different sites. Estimating local movements is further complicated by evidence that during the winter male Steller sea lions, like the California, migrate to B.C. waters from more southerly rookeries in California and Oregon, and may also migrate north from B.C. into Alaskan waters in summer. It is probable, too, that sea lions disperse into B.C. waters in winter from a very large rookery on Forrester Island just across the border in Alaska.

Although a great deal of data has been accumulated on the numbers of animals on the rookeries and other hauling-out sites, particularly from 1971 to 1984, these counts always underestimate the population. At any given time, some animals will be at sea and others ashore at sites outside British Columbia, or at sites frequented by only a few animals and not included in the survey. However, the counts, when critically examined, are believed to be sufficiently related to the actual population size to give a good measure of changes in population size over time. The best relative index of breeding population size is probably the number of pups counted, since these are virtually all produced on the rookeries. Few pup counts, however, were made early in the century, when most counts were of the total population. Counts made about mid-July are most complete because all pups have been born, and few animals have yet dispersed from the rookeries. Bigg (1985a) has developed a method of adjusting counts made earlier in the summer to allow for the pups not yet born. The adjusted early season counts appear to be acceptable estimates of total pup production.

Numbers Killed

The number of Steller sea lions on the B.C. coast appears to have fluctuated substantially since the early 1800s. Bigg (1985a) believes that during much of the 19th century, sea lion numbers were kept to a reduced level by Indians hunting for meat, hides, oil and other products. By the end of the century there were fewer Indians, and they were probably less dependent on sea lions for subsistence, with the result that fewer sea lions were killed, and their numbers began to increase. Bigg cites Newcombe et al. (1918) as stating that fishermen believed that sea lions were more abundant in 1913 than in the early days of the salmon fishery, that is, in the late 1800s.

This apparent increase led to organized hunting in 1912 and 1913, when about 7,400 sea lions were killed. After these episodes the sea lions were apparently left in peace until 1922. From 1922 until the beginning of the Second World War in 1939, sea lions were officially hunted quite vigorously; about 30,000 animals were reportedly killed, and the group of rookeries which was chiefly attacked was virtually eliminated (Bigg, 1984, 1985a). For the next 20 years the numbers of sea lions killed in official hunts were small (a few hundred per year), except in 1950, when about 2,000 animals were killed. Bigg believes that "substantial" although uncounted kills were made by the navy and air force during the Second World War in efforts to help the fishermen.

"Management" hunting under government control was resumed in 1958, and in the following year 3,388 kills were recorded. Hunting gradually tapered off after that year and finally ceased after 1968. The number of kills officially recorded during this period was about 11,000. Fisheries officials consider the number of kills reported an overestimate (Bigg, 1984, 1985a). Unlike the practice in commercial and research operations, kills were not always confirmed by recovering the carcasses; it is likely that many animals reported killed were missed or only wounded.

Relatively few sea lions have been taken in commercial hunts on the B.C. coast for their skins and meat as compared to those killed for management purposes. A few hundred animals were taken from 1913 to 1915 and from 1936 to 1939, but the principal commercial hunt took place between 1955 and 1966, when nearly 7,000 sea lions were killed. Animals killed for research purposes have totalled fewer than 700, and most of these were taken between 1958 and 1961. Fishermen have killed some sea lions throughout the whole period, but no estimate of the numbers exists. Table 22.1 lists the various kills, omitting the periods when few animals were taken.

Population Estimates

Between 1913 and 1916, several counts were made on most of the major rookeries, and the total number of Steller sea lions inhabiting them at that time was probably 11,000–14,000 (Bigg, 1985a; Pike and Maxwell, 1958). No further counts were made until 1938. By that time the population had been subject to kills of about 7,400 animals in 1912–1915, and 17,000 in 1922–1935, and the more intense killing of 1936–1939 was still in progress. Most hunting was concentrated on particular rookeries at any one time, and

Table 22.1
Major Kills of Steller Sea Lions on the B.C. Coast, 1912–1968

	Management	Commercial	Research	Average Total Per Year
1912–15	7,400	500	–	2,000
1922–35	17,000	–	–	1,200
1936–39	11,000	–	–	2,700
1940–45[a]	–	–	–	substantial
1950	2,000	–	–	2,000
1958–68	11,000	7,000	700	1,700

Source: Adapted from Bigg (1984, 1985a).

a. Substantial but undocumented kills by the armed forces.

consequently, effects were somewhat localized. From 1922 to 1935, hunting was concentrated on two rookeries in the Sea Otter Group of islands at about the centre of the B.C. mainland coast. By the end of the 1930s, these breeding colonies had been destroyed, although the sites are still occupied as non-breeding haul-out sites.

The intensive hunting which began in 1936 was concentrated on the offshore Scott Islands, to the north of Vancouver Island. The numbers of Steller sea lions on these rookeries had apparently been increasing between 1915 and 1936, but were reduced by the hunting carried out from 1936 to 1939. By 1938, the overall population on the rookeries seems likely to have been about the same as in 1913, that is, about 12,000 animals, although the numbers declined seriously on the Sea Otter Group (Bigg, 1985a).

There were further recorded kills in 1939 and 1950, as well as the uncounted kills conducted by the armed forces. The next counts were made in 1955 and 1956, and by that time the estimated numbers on the rookeries had dropped to 9,000–11,000. The rookeries on the Sea Otter Group had vanished, but there was a compensating new rookery on Sartine Island in the Scott Islands and an apparent increase in numbers at Cape St. James on the Queen Charlotte Islands. It has been suggested that the Sartine Island rookery was established by animals that hunting had driven off the other

rookeries, such as those on the Sea Otter Group. Heavy hunting occurred from 1958 to 1968, and by the time of the next counts, in 1961 and 1971, the estimated total numbers of Steller sea lions on the rookeries were reduced to about 4,600 and 3,500 respectively.

After hunting stopped in 1968, an increase in the size of the sea lion population might have been expected. No such increase appears to have taken place. Bigg's (1985a) count in 1982 recorded only 3,970 animals on rookeries.

On the counts of pups over this period Bigg (1985a) comments:

> *A comparison of pup production in British Columbia between 1971 and 1982 suggests that an increase in breeding stock may have occurred between 1977 and 1982 following stable pup production in 1971–77. However, no increase in postpups was recorded between 1977 and 1982 which suggests that the increase in pup numbers in 1982 may not be indicative of a true increase in breeding stock size. It is possible that pup survival in 1982 was better than usual.*

The principal counts of animals on the rookeries reported by Bigg (1985a) are summarized in Table 22.2.

If we use the pup counts as the best index of population size, then the relative size of the 1977–1982 population compared to that of 1956 is 1200/3250, representing a decrease to about 37%. The estimate of the total population in 1956 is 9,400 as compared with 11,000–14,000 in 1913, or a decrease to about 67% to 85%. If we ignore any changes in the proportion of pups to the total population between 1913 and 1956, these figures imply that the 1977–1982 population was about 25%–31% of the population in 1913.

The 1956 and 1971–1982 counts recorded the number of pups as about one-third of the total animals seen, but as noted earlier, counts on the rookeries underestimate the total population. Calkins and Pitcher (1982) have used available data on the age composition of the population, age at maturity, pregnancy rate and sex ratio, to draw up life tables for Steller sea lions. These tables can be used to estimate the ratio of pups to total population in an ideal situation. They indicate a total population of about 4.5 animals of both sexes and all ages (including pups) for each pup produced.

Table 22.2
Counts of Steller Sea Lions, British Columbia and Forrester Island, 1913–1982

	Total Steller Sea Lions			Pups	
	B.C.	Forrester Island	Forrester Island + B.C.	B.C.	Forrester Island
1913	11–14,000[a]	50–100	11–14,000	–	–
1938	12,000	–	–	–	–
1956	9,400	–	–	3,250	–
1961	4,600	2,400	7,000	2,000	1,100
1971–73	3,500	6,200	9,700	1,050	2,400
1977–82	4,000	5,500	9,500	1,200	–

Source: Bigg (1985a).

a. For rookeries and non-breeding sites.

The tables are based on a very small number of animals so that the estimates of mortality rates used contain large sampling errors. The estimates are very sensitive to assumptions about the variation of the mortality rate with age and to the method used to fit the survival curve to the data. Furthermore, the basic data were obtained from sea lions in the Gulf of Alaska. It does not seem likely that any significant errors will arise from this cause; the distances involved are not great, and some migration between Alaskan and B.C. waters is known to occur.

Examination of the original data kindly provided by Calkins and Pitcher suggests that the likely range of the ratio of total population to pups is 4.0 to 5.5. Thus the decrease in pups counted from 3,250 in 1956 to 1,200 in 1982 corresponds to a change in total population from about 13,000–17,800 to 4,800–6,600.

The Current Situation

Between 1913 and the late 1960s, the number of Steller sea lions breeding on the rookeries on the coast of British Columbia declined to about

one-quarter of the 1913 level. This decline was the result of an erratic series of government-sponsored kills undertaken to benefit the fishing industry. Since protection was applied in 1969, however, the rebuilding of the B.C. rookeries which might have been expected has failed to materialize. The causes of this failure are of particular importance to any attempt to assess the future of the Steller sea lion population on the B.C. coast.

Under present regulations, fishermen may kill sea lions if these animals are actively interfering in fishing operations. The regulations permit the individual fisherman to exercise considerable discretion. The Royal Commission does not know how many sea lions are killed under this dispensation, but the numbers killed are probably too few to be the main cause of the failure of the population to rebuild since protection was established. It seems desirable to require fishermen to provide a record of the number of sea lions they kill to the Department of Fisheries and Oceans.

The first point to be considered is the degree of change there has been in the total number of Steller sea lions frequenting, and using the food resources of, the B.C. coast. It is likely that this number, as distinct from the number breeding, has increased because of the growth, during the 1950s and 1960s, of the very large rookery on Forrester Island, just across the Alaskan border. Some of the animals from this rookery feed in B.C. waters, thus competing with the animals from Canadian rookeries. As Table 22.2 shows, the combined total for B.C. and Forrester Island rookeries increased by the 1970s, and may now be not very much less than the 1913 level.

Secondly, the California sea lion population visiting the southern coast of British Columbia has increased substantially since 1965 and may have influenced the Steller sea lion population through competition. There are a number of reasons for thinking that any such effect would be of minor significance:

- Most of the increase in California sea lions on the B.C. coast has occurred since 1980.

- The spread of California sea lions has been largely limited to the southern part of the B.C. coast.

- The California sea lions are only present on the B.C. coast for about half the year (Bigg, 1985a).

- The biomass of California sea lions in B.C. waters is small compared to that of Steller sea lions. The average weight of Steller sea lions is about

180 kilograms on the basis of weight-at-age data in Calkins and Pitcher (1982) and on age-distribution data provided by Pitcher (1985). Taking the central estimates of the total populations in 1956 and 1982 as 15,400 and 5,700 animals respectively, the biomass estimates are 2,772 and 1,026 tonnes. The most recent estimate is that 4,500 California sea lions are present for less than half the year. Allowing for the fact that only males visit British Columbia, the mean individual weight is about 180 kilograms (Mate, 1985), which is equivalent to an average biomass over the whole year of about 400 tonnes. This is small compared to the decline, since 1956, of about 1,750 tonnes in the biomass of the Steller sea lion population based on the B.C. rookeries.

No evidence has been found, as discussed in Chapter 23, that the carrying capacity of B.C. waters for sea lions has decreased as a result of reduction in the food supply. The principal food of Steller sea lions in this area is octopus, which is not subject to any commercial fishery, and there is no reason to believe that the numbers of sea lions have declined from any other cause. The main commercial species preyed on by sea lions (Chapter 24) are the Pacific herring and the various kinds of salmon. The herring declined temporarily between 1965 and 1970, but have since recovered, and populations have been generally at or above the 1951–1965 levels (Haist et al., 1985). A decline in the number of herring off southern British Columbia since 1980 is too recent to contribute to the post-1969 continuation of the low sea lion population. There is no reason to believe that there has been any reduction in the availability of salmon that would have a limiting effect on sea lions. Nor is there any good evidence of serious disease or pathological effects of pollution on Steller sea lions. In fact, there are more reported occurrences of this kind affecting the California sea lion off California, despite which that population continues to increase.

Another possible cause of recent mortalities has been noted in the discussion of the status of the northern fur seal. Entanglement in lost or discarded netting and other plastic debris is apparently contributing to a failure of the Pribilof Islands' fur seal population to rebuild as expected. There are also indications of adverse effects from the same cause on the Hawaiian monk seal. Bigg (1985a) reports seeing Steller sea lions with plastic debris around their necks, and the possibility of adverse effects on B.C. sea lions cannot be ignored. Reports do not suggest, however, that entanglement of sea lions occurs with sufficient frequency to make this possibility a strong hypothesis.

Comparison with adjacent areas presents a rather confusing picture. The Forrester Island rookery in southern Alaska has increased greatly since

the 1950s, although the 1983 count was slightly, perhaps not significantly, less than that of 1973 (Bigg, 1985a). In the central Aleutian Islands, on the other hand, Steller sea lions have been decreasing since 1960 at a rate of about 6% per year (Loughlin et al., 1984; Loughlin, 1984). Further west on the Aleutian chain, however, their numbers appear to be increasing.

No satisfactory explanation of the decline of Steller sea lions in the central Aleutians has been found. Some degree of population redistribution may be taking place. Braham et al. (1980) speculate that causes of the Aleutian decline may include a pathogen, the commercial harvesting of pups between 1970 and 1972, and interactions with commercial fishing activities.

The public impression of an increase in sea lions on the B.C. coast in recent years, despite the virtual stability of the Steller population, has arisen from the increase in the numbers of California sea lions and from a real increase in the numbers of Steller sea lions wintering in the waters off southeastern Vancouver Island, an area where the animals are much exposed to the public view. Since 1972, a number of new winter haul-out sites have been established in this region, and the numbers of sea lions counted on them in the month of February rose from 71 in 1972 to a peak of 983 in 1982; in 1984, the number had fallen to 328. This increase is the result of a shift in the distribution of wintering animals and not of any real increase in the population. Bigg (1985a) considers two possible explanations. One is an increase in food supply following the recovery of the herring stock after the crash in the numbers of that species in the 1960s. This view is supported by the fact that numbers of sea lions on some haul-out sites have declined again, between 1982 and 1984, coincident with a sharp decrease in the abundance of herring in this area (Haist et al., 1985). Bigg (1985a) states, "An alternative explanation . . . may be that the control programs kept many animals away up to the late 1960s. The species was frequently hunted in this populated region." It does not seem possible at this stage to determine to what extent either or both of these possible causes contributed to the increase in winter numbers of sea lions in this area.

Conclusions

1. The number of Steller sea lions occupying Canadian rookeries declined from 11,000–14,000 in 1913, when it was near its maximum, to about 4,500 in the early 1960s. The drop was a result of extensive hunting undertaken mainly for the purpose of "managing" the stock

for the benefit of the fisheries. The total Canadian population has declined from about 13,000–18,000 in 1956, to about 4,800–6,600 in 1985.

2. Since the cessation of hunting in 1969, the expected recovery in the breeding population of Steller sea lions has not taken place. The population remains at about 25%–30% of the 1913 level. A system should be introduced to require that records be kept by fishermen of their kills of sea lions that are interfering with fishing operations.

3. A very large rookery has developed on Forrester Island, just across the Alaskan border. If this rookery is taken into account, the combined B.C–Forrester Island population is now similar to, or a little less than, the 1913 B.C. population.

4. It seems most likely that it is the large increase in the numbers of Steller sea lions breeding on Forrester Island that has, by increasing consumption of the available food supply, prevented recovery of the numbers breeding on B.C. rookeries since 1969.

5. It does not seem likely that the northward expansion of California sea lions as winter visitors to B.C. waters has had a major effect on the Steller sea lion population.

6. There is no evidence that decline in food supply, caused, for example, by commercial fishing, has limited recovery of the population breeding on B.C. rookeries.

7. There is no evidence that disease or pollution has adversely affected the B.C. population of sea lions.

8. There is evidence that some Steller sea lions are becoming entangled in discarded or lost netting and other plastic debris, but it is not enough to indicate whether entanglement is causing mortalities on a sufficient scale to limit population as it apparently does for northern fur seals.

9. The apparent increase in the numbers of sea lions in B.C. waters, which has attracted much public attention, is partly the result of the spread northwards of California sea lions as winter visitors and partly of a redistribution of Steller sea lions southwards in winter. Both have moved into waters more frequented by people, that is, Georgia

Strait and around southern Vancouver Island. This redistribution may be a response to an increase in the abundance of herring in the area.

10. It seems likely that the Steller sea lion population in the region of British Columbia and the southern tip of Alaska is close to the area's carrying capacity. If so, further expansion (say, by more than 25%–50%) seems unlikely in the near future.

California Sea Lions

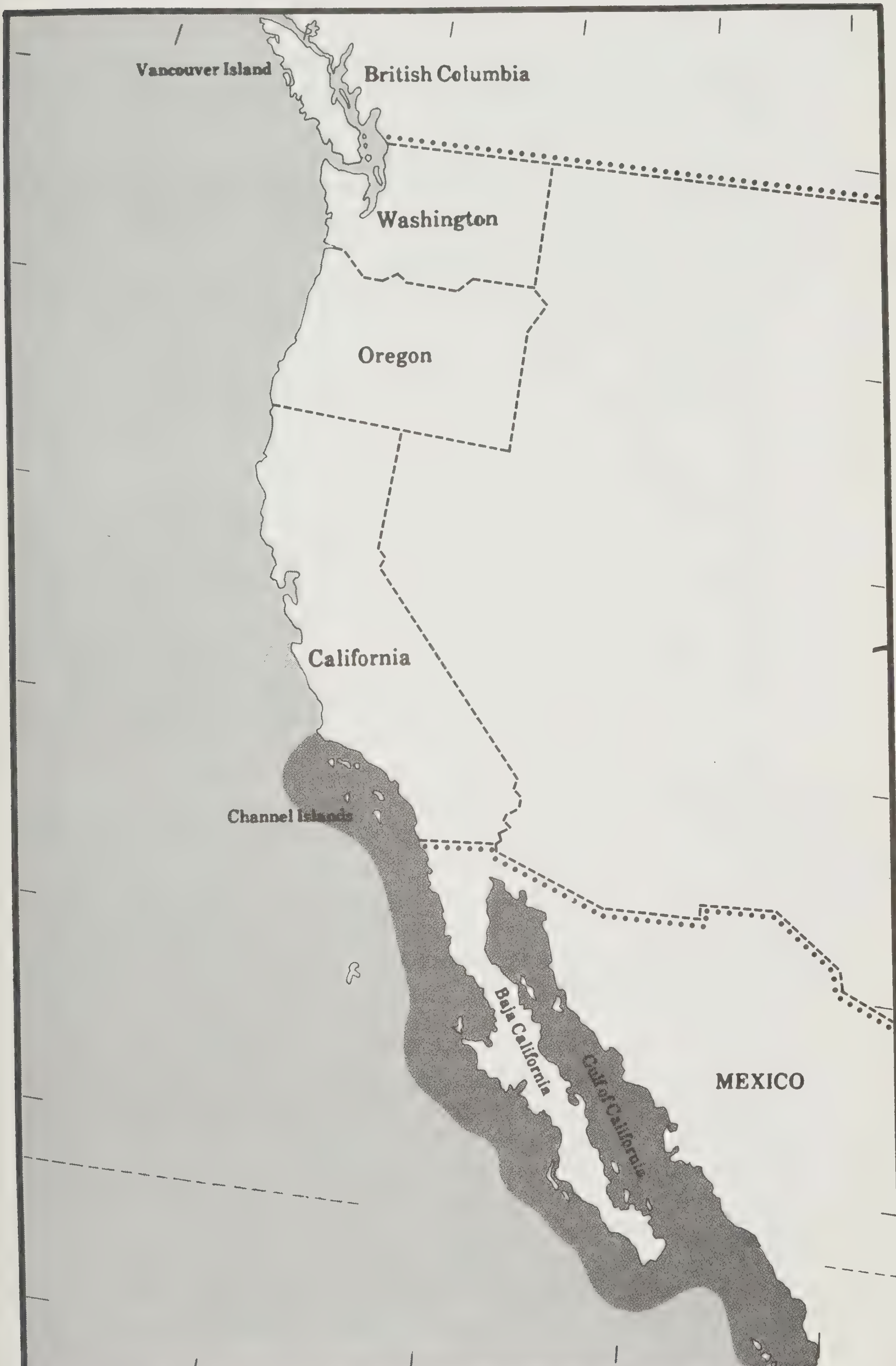
The Current Situation

The history of the California sea lion on the coast of British Columbia is very different from that of the Steller sea lion. While there are a few isolated records of the former species' appearance during the 1800s and early 1900s, it does not seem to have been seen regularly until about 1965, when a small haul-out site was established on Race Rocks in Juan de Fuca Strait. Especially since 1980, the numbers of California sea lions have increased, and by 1984, about 4,500 of these animals were counted in aerial surveys (Bigg, 1985a). Distribution is concentrated at the southern third of Vancouver Island, although there is one regularly occupied site as far north as Solander Island on the west coast. California sea lions seem to have increased sharply in numbers between 1982 and 1984, while the number of Steller sea lions wintering round southeastern Vancouver Island declined during this period.

The appearance of California sea lions in recent years is not, however, an extension of the breeding range of the species, which continues to be limited to California and Mexico (Figure 22.3). The animals in B.C. waters are all males that migrate northward after the breeding season. Most of these animals arrive between October and December, and they have nearly all gone by May; in a local movement, a number of animals have been recorded entering the Fraser River in early May in pursuit of spawning eulachon.

Bigg (1985a) has reviewed the background of this increase in the California sea lion in the waters off British Columbia, as follows.

Figure 22.3
Breeding Range of California Sea Lions



Source: King (1983).

The number of California sea lions off Vancouver Island increased 10-fold between 1972 and 1984, with most of the increase apparently taking place since 1980. The species did not increase the northern range in association with the sharp increase in numbers since the late 1970's. None was seen during an aerial survey for Steller sea lions around northern Vancouver Island, from Denman Island to Solander Island, during 7 March 1984. Presumably, not all individuals present off Vancouver Island were counted. Some may have been at sea feeding or swimming between sites. The censuses hence provided an estimate of minimum numbers, and annual trends.

An increase in the number of California sea lions off Vancouver Island was expected over the past 50 years, because the breeding population off California has grown steadily. Only about 400–1,000 California sea lions were seen off southern California during the early 1930s, following severe depletion for commercial purposes (Bonnot 1928; Barthomolew and Boolootian 1960). Thus, few animals could have migrated into southern British Columbia early in this century. By 1975, the population off southern California had increased to at least 27,000 (Mate 1977), and since then has continued to increase at a rate of about 5%/yr (DeMaster et al. 1982).

The increase observed off Vancouver Island during the 1980's was much larger than the annual rate of increment for the breeding population off California. Hence, a sudden shift to a more northern migration appears to have occurred in the southern population. One possible explanation is that the population in wintering areas south of British Columbia grew past a critical level of crowding or competition for food and as a result suddenly some males shifted their winter distribution northward. DeMaster et al. (1982) suggested growth of the breeding stock may be slowing due to density dependent factors. Perhaps in approaching maximal numbers, the population expanded the use of the northern range. If this explanation is correct, then the size of the population

> *in British Columbia can be expected to remain large, or perhaps continue to increase in the future if the breeding population off California continues to increase in size. Another possibility is that recent increases in coastal water temperatures encouraged the species to move more northward. Bartholomew (1967) suggested that the northern limit of the breeding range of the species was restricted to southern California by warmwater distribution. In 1982–83, the El Niño current caused a more northly flow of warm water from tropical areas to the coast of British Columbia (Tabata 1984). A longer warming trend also took place along coastal waters of British Columbia between about 1972 and 1981 (Dodimead 1984). Temperature could influence the winter distribution of California sea lions through changes in food supply, or changes in the metabolic costs of thermoregulation. If increased water temperatures caused the numbers of this species to increase in British Columbia, then numbers should decrease over the next few years. El Niño is now diminishing, and a decreasing trend in the long-term temperature of coastal waters is expected.*

It is thus not possible to forecast whether the large numbers of California sea lions off British Columbia will be maintained, increase or even decrease. If the increase in their numbers has been the result of temperature effects, a decrease in the near future is likely as the El Niño current dies away and the present trend reverses. If, however, the additional animals have been pushed northward by the expansion of the breeding population in California and Mexico, the numbers are likely to stabilize or possibly even to increase.

If for any reason, however, it becomes desirable to reduce the numbers of California sea lions in B.C. waters, attempts to do so by hunting would be less likely to be effective than they have been in the past for the Steller sea lion. It has been possible to reduce or even destroy breeding colonies of the latter animals by killing the breeding females. For California sea lions, only a part (perhaps 20%) of the male, and none of the female, population would be exposed to hunting here. It is impossible to be sure what the effect on overall pup production would be of removing a proportion of the males and no females, but it is unlikely to be great.

Conclusions

1. Male California sea lions have become conspicuous winter visitors to the southern B.C. coast in the last few years; up to about 4,500 have been counted.

2. It is likely that the expansion of the main breeding population off California and Mexico is the main cause of their abundance off British Columbia, but climatic conditions, including the recent El Niño phenomenon, may have contributed.

3. Since California sea lions do not breed in Canada, and only a small proportion of the male population visits B.C. waters, no actions taken in Canada are likely to have significant effect on the numbers of visitors, except possibly on a localized basis and within the season in which action is taken.

Harbour Seals

The harbour seal is widely distributed throughout the temperate regions of the Northern Hemisphere. (See also Chapter 21.) It is essentially a coastal animal rarely found more than 15 kilometres from land (Fisher, 1952). It does enter fresh water, particularly when following migrating fish such as salmon, and groups may become established in rivers and lakes as far as 300 kilometres from salt water (Fisher, 1952).

Exploitation

Bonner (1979) has assembled published information on the numbers of harbour seals recorded in the various ocean areas. These seals total about 380,000–400,000 animals excluding those in the Baltic Sea, Greenland, the eastern United States, and the Asiatic coast of the Pacific Ocean. On the eastern Pacific coast, harbour seals extend from northern Alaska to Baja California (Figure 22.4). The greatest number (260,000) are to be found in Alaska (Bonner, 1979), but these seals are numerous as far south as Oregon.

On the B.C. coast, harbour seals have fluctuated in numbers, probably as a result of varying levels of killing by fishermen and hunters. Fishermen anxious to protect their gear and catches of fish have probably been

Figure 22.4
Distribution of Harbour Seals in the North Pacific

Source: King (1983).

killing some harbour seals since the early days of European settlement. No useful data are available concerning the number of seals killed in this way. From 1914 to 1918, 1928 to 1934, 1936 to 1940 and 1941 to 1964, the Canadian government operated a bounty scheme in response to demands made by the fishermen. Bounties claimed each year from 1928 to 1964 have ranged between 2,000 and 6,000 and averaged just over 3,000 (Bigg, 1969). Bigg estimated from experience and on the basis of conversations with hunters and DFO officers that an equal number of seals were killed for which no bounties were claimed, either because they could not be retrieved or because no effort was made to obtain the bounty. On the other hand, Fisher (1952) observed that some bounties may have been fraudulently claimed, either by substituting sea lion noses (on which no bounty was paid) or by importing noses from areas in the United States where no bounty, or smaller bounties, were paid. Such cases were probably few, however, compared to the numbers of harbour seals killed without the payment of bounties.

From 1964 to 1969, there was also a commercial hunt for harbour seals on the coast of British Columbia to take pelts for the European market. The numbers of pelts taken are not known with certainty, but they probably amounted to about 10,000 (Bigg, 1985a). Large kills were made in 1964 and 1965; after these years the number of kills declined rapidly, because of a decline in the markets. Since 1970, the harbour seal has been protected on the west coast of Canada.

Population Estimates

Harbour seals can be counted by aerial surveys because they habitually haul out on reefs and inter-tidal sandbars at low tide. Difficulties in basing absolute population estimates on such counts are the result of uncertainties about the proportion of animals hauled out in a given area at the time the count is made. A number of experiments have aimed at obtaining data on this point through observing radio-tagged animals. Pitcher and McAllister (1981) observed 35 animals in Alaska over a period of several months. They found that the proportion of the days on which a seal hauled out varied for different groups of animals from 16% to 80%, and they concluded that the "average number of seals hauled out . . . probably represented between about 35% and 60% of the population." They found these figures consistent with other researchers' observations. Harvey (1984) found that radio-tagged animals in Oregon were visible only 9% of the time. He considers this low figure a consequence of the small size of the sample and believes that in general counts would represent about half of the animals

present (Harvey, 1985). It seems that there are great differences in the proportions of harbour seal populations hauled out, both from time to time and in different areas. It is not appropriate, therefore, to apply any single standard figure in calculating population estimates from direct counts. Bigg (1985b) considers that around southeastern Vancouver Island, where there are a great many haul-out sites, most of the animals will be seen, but that in the long steep-sided inlets of the mainland coast, there are few haul-out sites and consequently few seals will be seen hauled out, although they may be observed in the water.

Bigg (1985b) stated that substantial data have been gathered by the Pacific Biological Station on counts of harbour seals on the B.C. coast. These data relate to two areas, one off southeastern Vancouver Island and the other off the Skeena River on the northern B.C. coast. For southeastern Vancouver Island, Bigg estimates that about 2,000 seals of all ages were hauled out by the end of the pupping season in 1973, and that by 1983, numbers had increased to 6,300. These estimates were derived from taking a composite of regions within the study area, as well as a combination of years, and by giving consideration to abundance trends. As mentioned above, Bigg believes that in this area, under the conditions of the study, almost all the seals would have hauled out so that the numbers actually present would not greatly exceed the numbers counted. The 1983 population could be as high as 7,500.

Off the Skeena River, the counts of harbour seals of all ages totalled 400 near the end of the pupping season in 1977; they totalled 660 in 1983. It does not seem possible to use these figures to obtain useful estimates of the true population size in the study area, but the figures do indicate the relative change in the numbers of harbour seals between 1977 and 1983. Bigg (1985b) provided an estimate of the total B.C. population of these animals, based on the southeastern Vancouver Island counts. In so doing he used the following reasoning:

> *At least 6,300 animals were seen here in 1983. Let's assume that the density of seals here was the same in other areas of British Columbia, which is a possibility. Based on having flown over much of the coast of British Columbia many times, and hunted or observed seals in many areas, I don't think that density, if it varies, is greater in other areas. Additional support for this possibility comes from a comparison between areas of kills*

> *per distance of coast-line. Fisher (1952, p. 50) indicated that during 1942–1947 about 15% of the total kills in British Columbia came from southeastern Vancouver Island. This figure is about the same proportion that the coastal distance around southeastern Vancouver Island is of the total coast-line of British Columbia. Thus, using the multiplier, a total current population of about 42,000 is suggested.*

He points out, too, that if the number of harbour seals in this study area was actually 7,500, the total population estimate would rise to about 50,000. Similar reasoning would provide an estimate of the total B.C. harbour seal population of 13,300–16,000 animals in 1973.

Several other more indirect methods of obtaining estimates of the B.C. harbour seal population have been used. The earliest attempt to establish an estimate was made by Spalding (1964). On a rough assumption of an average of one harbour seal per mile of coastline, he estimated a population of 17,000 seals. He also quotes some professional bounty hunters as estimating the harbour seal population at 20,000.

Bigg (1969) used another method to estimate the harbour seal population. This method was based on the assumption that over the 50-year period (1914–1964) when a bounty kill was taken, the seal population reached and maintained stability. This assumption is reasonable, since the age and fecundity structure of the population is such that generation time (mean age of female when a pup is born) is about 8.5 years (Bigg, 1969), so that five or six generations elapsed during the period in question, and the number of animals killed annually did not vary greatly. If it is further assumed that the number of unrecorded kills and the annual natural mortality of the harbour seals were each equal to the bounty kill, the total number of deaths would be about 9,000 a year. Using the data on the proportion of females that are mature (55%), the proportion of mature females that are pregnant (88%), and the proportion of females in the total population (53%), Bigg calculated that the population would have comprised about 3.9 animals for each pup born. Since the number of deaths and the number of pups born would be equal, this figure corresponds to a total population of about 35,000 harbour seals during the stable period of roughly the late 1950s and the early 1960s.

These figures correspond to a total instantaneous mortality rate (Z in standard fisheries science notation) of about 0.3. Since it is assumed that

natural deaths cause one-third of the mortality, the corresponding instantaneous natural mortality rate (M) would be 0.1. This is virtually the same value as that obtained by Pitcher and Calkins (1979) for male and female harbour seals in samples in which the animals' ages were determined when they were taken in Alaska. It is also the same as the central value identified in Chapter 21 for the harp seal, which has been more extensively studied. The two species are similar in size, although the harbour seal is slightly smaller, and the average weight of adult west coast harbour seals is about 70% of that of the average harp seal. Since there is a general tendency in marine animals (Ohsumi, 1979, for cetaceans; Pauly, 1980, for fish) for natural mortality rates to increase as the average size decreases, one might expect the harbour seal to have a slightly higher mortality rate than the harp seal. This difference would probably be small compared to the degree of uncertainty in the estimates of the mortality rate for harp seals. The assumptions used to determine this estimated mortality rate are thus reasonably consistent with what is known of the more extensively studied harp seal.

Another estimate of the size of the harbour seal population is based on observations of the rate of population increase after bounty and commercial hunting were discontinued at the end of the 1960s. The figures cited above show an average annual rate of increase of 12% off southeastern Vancouver Island between 1973 and 1983, and a corresponding rate of 9% off the Skeena River between 1977 and 1983. These increases reflect the survival of animals that would previously have been killed. The number of bounties paid (3,000 a year) underestimates this number, but the total number of animals believed killed by hunters and fishermen (6,000 a year) would probably represent an overestimate of the increase in survival, since some killing probably still occurs despite legal protection. On this basis, assuming an average annual rate of increase of 10%, the population size in the stable period before protection began in 1969 would amount to 30,000–60,000 harbour seals. The estimate of 42,000 given above, which was based on different data, falls in the middle of this range and thus is not inconsistent with it.

Population Trends

The population estimates reported in the preceding section are summarized in Table 22.3. Allowing for the tenuous basis of the Spalding estimate, there is no great discrepancy among the three figures relating roughly to 1960. It is difficult, however, to reconcile these figures with the 1973 and

Table 22.3
Harbour Seal Population Estimates, 1960–1983.

Year	Estimate (1000s)	Method	Source
c. 1960	17–20	Average number/mile	Spalding (1964)
c. 1960	35	Recorded deaths and population structure	Bigg (1969)
1960s	30–60	Recorded deaths and rate of increase	Present Report
1973	13–16	Extrapolation from 1973 count	Present Report
1983	42–50	Extrapolation from 1983 count	Bigg (1985b)

1983 estimates. The latter indicate a rate of population increase of about 10% between 1973 and 1983, and at first sight it is reasonable to extrapolate this back to 1969, when the species came under protection. If this is done, the 1960 estimates are too high compared with those for 1973 and 1983.

The greatest uncertainty in the derivation of the second and third estimates for 1960 lies in the number of harbour seals killed; the other main components – the population structure and the rate of population increase after hunting was discontinued – are both based on fairly direct observations. Bigg's (1969) estimate of the total hunting kill is twice the number of bounties claimed. A minimum estimate of the kill would be the 3,000 bounties paid. Using this figure would reduce the population estimate to 23,400. For the third 1960 estimate, the corresponding figure is 30,000, as shown in Table 22.3. Since this adjustment does not entirely remove the discrepancy, we must consider the level of uncertainty in the rate of increase in the population. The independent estimates for the rates of increase of the Vancouver Island and Skeena River segments of the harbour seal population are not very different; nor are they inconsistent with estimates for other seal

populations. For example, estimates of natural rates of increase for northern fur seals of about 8% and for northern elephant seals of about 10%, are reported elsewhere in this chapter. The estimate of the annual rate of increase thus seems likely to be subject to relatively smaller uncertainties than is the estimate of numbers killed prior to protection.

There are also uncertainties relating to the period over which the increase has operated. A proportional change of population size by a factor of 3.15 was observed off southeastern Vancouver Island between 1973 and 1983. For the Skeena River area, the corresponding factor was 1.65 between 1977 and 1983; this factor, if projected, would be equivalent to 2.3 between 1973 and 1983.

Assuming that these figures are approximately correct, we can only speculate concerning the reasons for the discrepancy when comparisons are made with the 1960 population estimates. Possible contributing factors include:

- errors in the population estimates, particularly for 1960;
- a population decline, possibly by a factor of about 2, between 1960 and the discontinuance of hunting in 1969;
- a lag in the commencement of population expansion after 1969;
- changes over time in the ratio of the harbour seal population of southeastern Vancouver Island to the total B.C. population.

Considering the various uncertainties, any statement about past and present populations of harbour seals on the B.C. coast should be limited to the following:

- in the 1960s the population probably consisted of 20,000 to 30,000 animals;
- the current population probably stands at 45,000 to 60,000 animals.

Whether or not harbour seals are currently increasing at about 10% per annum, they cannot continue to do so indefinitely even in the absence of hunting. If information had been available on the numbers of harbour seals in the early days of European settlement before serious hunting began, or before the bounty scheme was started in 1914, it might have been possible to

use those figures to estimate the potential expansion of the population in the absence of hunting or other adverse effects. Unfortunately, no such data are available.

Future Prospects

Natural factors which could influence the equilibrium level include changes in numbers of predators, in incidence of disease, and in climatic conditions. No evidence has been adduced suggesting that any of these changes have occurred on a significant scale.

There are also at least three ways in which human activities could adversely affect the harbour seal population. The rate at which that population has been increasing, at least during the 1970s, suggests that none of these factors caused by human activities has had any major effect as yet.

The first possible factor is the influence of fishing on the food supply of the seals. Harbour seals, however, are opportunistic feeders, able to change to other foods as particular prey species become scarce; moreover, about half their food on the B.C. coast consists of animals of little commercial importance. The two main commercial groups on which the harbour seals feed are salmon and herring. There is no indication that there has been any significant decrease in the overall abundance of salmon since the end of the 1960s (Archibald and Graham, 1981), when harbour seals increased rapidly. Herring have generally been as abundant since 1970 as they were prior to a temporary decline which occurred in the late 1960s, in part, at least, as a result of over-fishing (Haist et al., 1985).

Secondly, there is reason to suppose that northern fur seals have been seriously affected by entanglement in discarded fishing nets and other plastic debris. It is also possible that sea lions have been affected in the same way, although to a lesser extent. There are few records, however, of harbour seals becoming caught in such debris, perhaps because of differences in their behaviour or in the abundance of debris in the waters they inhabit. At present, it seems unlikely that harbour seals are significantly affected by this debris.

A third and more serious cause for concern may be pollution, particularly by chlorinated hydrocarbons. In some relatively enclosed waters such as the Baltic Sea and parts of the North Sea, adverse effects of pollution on the reproduction of harbour seals are well documented (Van Haaften, 1974).

Adjacent to the B.C. coast is Puget Sound, where birth defects and pup mortality in harbour seals, possibly as a result of PCBs and DDT, have been recorded (Calambokidis et al., 1978). No direct evidence of effects of this kind has been found on the B.C. coast. Fortunately much of this coast is bathed by oceanic waters and is not subject to concentrations of localized origin. However, the distribution of pollutants is so widespread in the ocean that long-term effects on the harbour seals cannot be deemed impossible.

Conclusions

1. The current population of harbour seals is large and possibly growing; it is probably in the range of 45,000–60,000 animals.

2. Unless it has stabilized very recently, the population is still increasing, probably by about 10% per annum.

3. It is not possible to determine at what level the population will stabilize if it continues to be protected.

4. Hunting for bounties and hunting by fishermen in the years prior to 1970 did not endanger the harbour seal population, since it remained capable of a rapid natural increase when hunting ceased.

5. Unless the population has already been affected by changed environmental conditions, it can sustain an annual kill of at least 3,000 animals, and perhaps as many as 6,000, without risk.

6. The environmental effect caused by humans which seems most likely to have an adverse impact on the harbour seal population is pollution, particularly by chlorinated hydrocarbons, but there is no evidence of any significant effect of these pollutants at present.

Northern Elephant Seals

The northern elephant seal does not breed on the Canadian Pacific coast and rarely comes ashore there. It now breeds on offshore islands along the coast from central Baja California to central California. It disperses extensively along the coast from the breeding grounds in a northward direction. Guiget (1971) reported that the northern elephant seal was still rare off

the B.C. coast, although its numbers were increasing . The Department of Fisheries and Oceans stated in its submission to the Royal Commission that young of the year are seen off the west coast of Vancouver Island in late winter and spring, and that adult males are seen throughout coastal regions in summer (Canada, DFO, 1985).

Population Status

The species was originally abundant off the coasts of Baja California and California. From about 1800, it was heavily exploited for oil from the blubber and, by 1892, was on the verge of extinction; the number of animals surviving was not more than 100 and may have been much lower (Le Boeuf, 1979). It was then left in peace, and by about 1975, the numbers had built up again to about 45,000, at an average rate of increase of about 10% per year (Le Boeuf, 1979). It provides a good example of the ability of some species of seals to rebuild their populations from very low levels if they are not hunted.

Protection

No northern elephant seals have been killed off the coast of British Columbia for commercial or control purposes during this century, and these animals have been protected under the federal *Fisheries Act* since 1970. It is, of course, possible that some animals have been killed by fishermen, but no evidence is available on this point.

Conclusions

The northern elephant seal does not breed in Canadian waters, and only small numbers visit. It has no discerned impact on local fisheries and is currently protected. There seems no need for any further action at present.

Appendix

Appendix 22.1. Method of Calculating Average Rate of Increase from Initial and Final Population Size and Total Catch for Northern Fur Seals

The model assumes that the fur seal population changes over the period of observation by a constant instantaneous rate (Z). This rate is made up of two components, an instantaneous fishing (or hunting) rate (F) and the rate at which the population is "trying" to increase; that is, the rate (I) at which it would increase if there were no killing. If one assumes that these processes are continuous over a period of years, one can apply standard population-dynamics procedure. If the population changes from N_0 to N_t in a time period t during which a catch C is taken, then we can write:

$$
\begin{aligned}
Z &= \ln(N_0/N_t)/t \\
C &= F(N_0 - N_t)/Z \\
F &= CZ/(N_0 - N_t) \\
I &= F - Z
\end{aligned}
$$

The following table, indicating population and catch sizes in 1,000s, shows the values used in calculating the figures given in this report, (the p is 42 years for the period 1868–1910):

N_0	N_t	C	Z	F	I
2	.3	5.0	.045	.133	.088
2	.3	7.5	.045	.199	.154
3	.3	5.0	.055	.102	.047
3	.3	7.5	.055	.152	.097

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Chapter 23

Indirect Effects on Seals

Most of the interactions between humans and seals arise directly or indirectly because both are functioning as top-level predators in the same environment. Two of the most direct interactions occur when humans function as predators, using seals as a resource, and when human predation on other marine resources is affected by the competing predatory activities of seals. These interactions are discussed at some length in other chapters. This chapter considers other ways in which human activities may be exercising an effect on seals. The four questions which seem to require most consideration are the following:

- What effect has human exploitation of fish stocks on the seal populations preying on those stocks?
- What effect does the incidental killing of some seals in fishing operations have on seal populations?
- What effect has environmental pollution of human origin on seal populations?
- What impacts on seal populations could arise from development in the Arctic?

Reduction of Fish Stocks

Competitive Effects

Many commercial fisheries have seriously reduced the abundance of the fish against which they operate, sometimes sufficiently to destroy the fishery itself. At first sight it would appear that such reductions would seriously affect any marine mammals, including seals, which fed on these fish. In practice, however, no substantial evidence of any such effects has been forthcoming. Beverton (1985), for example, comments on the conclusions of a major international workshop on marine mammals and fisheries, held at La Jolla, California in 1981, under the auspices of the International Union for

the Conservation of Nature and Natural Resources (IUCN) and the United Nations Environment Programme (UNEP): "The Workshop was unable to find a case in which a fish-eating marine mammal had been adversely affected at the population level by interaction with a fishery." It cannot be assumed, however, that because no such cases have been identified, it must follow that they do not occur. As Northridge (1984) points out, we not only need to obtain much more data on the food of marine mammals, but we also need to know more about their feeding strategies as they respond to changes in the nature and distribution of their potential prey, and more about the inter-species population dynamics of the species concerned.

Nevertheless, there are several reasons why reduction in the abundance of certain prey species by commercial fishing may not necessarily have an identifiable effect on a seal population. In the first place, most seals are opportunistic feeders, able to turn to other available fish or invertebrates if one of their principal food species is reduced in abundance by human or natural causes. Secondly, migrating species, such as the harp and northern fur seals, may feed on different prey at different stages during their seasonal wanderings. Thirdly, neither the seals nor the commercial fisheries usually take only a single species; both take a variety of species which also sustain predator-prey relationships among themselves. Thus, part of the effect of the commercial fishery may be to remove predators on a prey species which is important to seals and so benefit them; a variety of such relationships is possible (Beverton, 1985). Fourthly, the seals and the fishery may be concentrating on the prey at different life stages; the seals may actually benefit if the fishery takes older fish that prey on younger age groups which are also eaten by the seals. This seems to happen with northern fur seals feeding on walleye pollock in the Bering Sea. Fifthly, provided prey abundance remains above a certain level, the individual seal may be able to obtain as much as its feeding behaviour will enable it to take, and any reductions in prey abundance above that level may have little effect on the amount that the individual consumes, and therefore on the benefit obtained by the seals.

Thus the Royal Commission can only conclude that while reduction in the abundance of fish that are important to seals as food may, in some circumstances, have an adverse effect, such negative relationships do not necessarily occur, and they have not been clearly identified among marine mammals as a whole.

Harp Seals

Some studies on this question have been undertaken for two of the most important seal species within the Commission's area of interest. Lavigne (1982) refers to evidence of a marked decrease in stored energy (blubber) in whelping female harp seals since the collapse of the capelin in the northwest Atlantic in the late 1970s. Recent studies have suggested that part of the decrease in capelin biomass is due to natural changes in year-class strength (Leggett et al., 1984) rather than to heavy fishing. Bowen (1985), in reviewing the situation in the light of additional data on fluctuations in the abundance of capelin, concluded that "the hypothesis that increased commercial fishing for capelin was responsible for a decrease in female [harp seal] condition is not supported by available data," and that "there is no evidence that commercial fishing in the 1960's and 1970's had a significant detrimental effect on the food available to harp seals, and hence on population growth."

Northern Fur Seals

The possible effect on the northern fur seal of the large fisheries which developed in the Bering Sea in the 1970s, especially for walleye pollock, has been considered in Chapter 22 on the status of the northern fur seal: there is no evidence to suggest that the fishery has contributed to the current declining trend in the fur seal population through any effect on the available food supply. If such an effect had been occurring, the density-dependent population parameters of growth and mortality would have taken values appropriate to a population at its carrying capacity. On the contrary, a number of these parameters are now at about the same values that they stood at in the 1920s, when the population was growing rapidly (Fowler, 1985).

The walleye pollock is unusual, but by no means exceptional, in that large and medium-sized pollock are among the most important predators on medium-sized and small pollock. Swartzman and Haar (1983) have shown that in the early stages of the development of the fishery, in the mid-1960s, the most abundant age groups were four- and five-year-old fish, but that by 1974 the most abundant age groups were two- and three-year-old fish. Apparently, the later age composition represents not only a change in relative abundance, but also a real increase in the abundance of the younger fish as a result of reduced cannibalism by the older fish. This change provided a larger food supply for the fur seals, which eat mainly younger fish.

Since 1980, the situation has changed again; Bakkala et al. (1984) report that, following poor recruitment of young fish into the population, older fish are again dominant.

Harwood (1983) also points out that a commercial fishery which tends to reduce the average size of the fish in the population may benefit those marine mammal populations which prefer smaller prey than do commercial fishermen. This generality applies to most seals. Even in such a heavily fished area as the North Sea, the total biomass of fish has changed little, despite the very heavy fishing intensity (Hempel 1978). The main effect of fishing has been to deplete the most valuable or most vulnerable species of fish, and to shift the size composition of these populations downwards to smaller fish.

Effects of Fisheries on Seal Predators

There is one other way in which a commercial fishery may possibly exercise a fairly direct and beneficial effect on a seal population. This is where the fishery reduces the numbers of a major predator on seals. Only one such possibility has come to the Commission's attention. Brodie and Beck (1983) have pointed out that the numbers of large sharks, especially of white sharks, off the east coast of Canada have probably decreased as a result of their capture, both in direct shark fisheries and incidentally in longlining for swordfish. This probable decrease is a fairly recent development, beginning about 1960, and the authors suggest that it may have contributed to the concurrent increase in grey seals, particularly on Sable Island, which lies at the centre of the area of the shark fisheries. Sharks are known by direct observation to be frequent predators on grey seals near Sable Island.

Incidental Kill of Seals in Fishing Operations

Chapter 25 deals with the fishing industry's losses of fishing gear caused by seals trying to take fish caught in nets or on lines. Some of these seals are killed as a result of this activity; they may become entangled in the gear and drown, or they may be killed deliberately by fishermen. Seals may also be accidentally entangled in fishing gear even when they are not trying to take fish. This section reviews what is known about the significance to the maintenance of seal populations of incidental mortality due to active

fishing gear. Mortality from abandoned and lost gear is reviewed in a later section of this chapter. Unfortunately, very little useful data on this problem seem to be available. Studies aimed at collecting quantitative data on the losses that seals cause to fishermen generally do not include records of the number of seals killed in the process. This applies, for example, even to the very thorough study undertaken by the Eastern Fishermen's Federation (Farmer and Billard, 1985). In particular, the Royal Commission has received no useful information on the numbers of grey seals that die in the course of encounters with fishing operations, in spite of the widespread prevalence of such encounters.

Harp Seals

Several witnesses, in their briefs to the Royal Commission, stated that following the great curtailment of the harp seal hunt in the last few years there had been an increase in the numbers of young harp seals becoming entangled in fishing nets (Rompkey,1985; Barker,1985; Wilderness Society of Newfoundland and Labrador, 1985). Such evidence is anecdotal – for example, one fisherman caught 38 seals in his nets in one day – and does not provide a basis for an estimate of the total numbers of seals killed in this way. Lien (1985), in a letter to the Royal Commission, provided some rather more detailed information. On the basis of information obtained incidentally to surveys of whale and shark entrapments, he estimates that the incidental kill of harp seals by Newfoundland and Labrador fishermen rose from about 1,000 per year in 1979–1982 to about 5,000 in 1984. This suggested fivefold increase may be compared with the population estimates treated in Chapter 21. The best estimate of harp seal pup production in 1978 was about 300,000–350,000, and no major change is likely to have occurred since that time. From 1973 to 1982, the number of pups killed in the Front and Gulf regions combined ranged between 98,000 and 178,000, with a mean of 130,000 (Cooke et al., 1986, Appendix, Table 4). From a pup production of 300,000 to 350,000, the number of survivors after a kill of 24,000 (that of 1984) would be 1.5 to 1.6 times that after a kill of 130,000. The reported increase in young harp seals becoming entrapped in nets in the last few years is therefore considerably greater than would have been expected on the basis of the population estimates. Since no detailed records of the numbers becoming entrapped are available, it is not possible at present to pursue the matter further. No information at all is available on the numbers of harp seals being caught in fishing gear on parts of the Canadian coast other than Newfoundland and Labrador.

In the review in Chapter 25 of the damage caused by seals to fishing gear and catches, it is noted that an estimated 10,000 harp seals were drowned in gill nets off northern Norway each year in the 1979–1981 period (Bjørge et al., 1981). Another source (Wilderness Society of Newfoundland and Labrador, 1985) stated that annual deaths in 1984 probably amounted to 15,000 on the Finnmark coast of Norway. All the estimates of the numbers of incidental deaths of harp seals are small compared to the numbers that used to be killed annually in the hunt and to the natural rate of increase of this stock.

Pacific Coast Seals

The Royal Commission received no useful information about the mortality of Pacific coast seals in Canadian waters caused by fishing gear, although certainly some harbour seals and sea lions, and possibly a few fur seals, die in this way. DeMaster et al. (1982) provide an estimate of the annual kill of California sea lions off the California coast. This kill amounted to about 1,500 animals, of which 60% were caught in shark gill nets and nearly all the remainder in halibut gill nets and on salmon troll gear. Since pup production of this species amounts to about 20,000 annually, the incidental kill, as a proportion of the total population, seems likely to be much higher for this species than for harp seals. The numbers of California sea lions have been increasing in recent years in spite of this kill.

Although there is good evidence of mortality in northern fur seals caused by entanglement in discarded netting and other plastic debris, there is much less evidence of their becoming entangled in operational fishing gear. Some are caught in the very extensive Japanese gill-net fishery for salmon in the north Pacific Ocean, but it seems unlikely that they total more than a few thousand. Lander and Kajimura (1982) quote Fukuhara (1974) and Nishiwaki (pers. comm.) as estimating the kill at 3,150–3,750 and 7,000 respectively. Fowler (1982), however, on the basis of more recent data, reports estimates in the range 100–1,000 and suggests that this figure is probably declining as a result of shifts in the areas fished. This mortality seems to be small compared either to the commercial harvest of males or, apparently, to the numbers of fur seals dying as a result of entanglement in discarded netting and other plastic debris.

Environmental Pollution

Three types of pollution of the marine environment can be identified as having possible effects on seal populations. They are:

- underwater noise pollution;
- chemical pollution;
- pollution with plastic debris.

Underwater Noise Pollution

Underwater noise pollution derives from such sources as ships' engines and the detonations used in seismic sounding. It seems to be of relatively little significance to seals, although it cannot be entirely ignored. It almost certainly has much less effect on seals than on the other large group of marine mammals, the cetaceans (whales, porpoises and dolphins). The reason is that seals depend less on sound for determining their position, for finding their food, and for communicating with one another than do cetaceans. Nevertheless, seals cannot be unaffected by some of the stronger sound effects which humans inflict on the marine environment. As Bonner (1982) says, "Seals within the range of underwater detonation used in seismic surveys must suffer acute discomfort if not physical damage." Terhune et al. (1979), quoted by Bonner (1982), have shown that there is a marked decrease in harp seal underwater vocalizations after a vessel with running engines arrives in the vicinity. The significance of these vocalizations to the seals is not known,and it is therefore impossible to assess the nature of the impact of the vessel's noise on these animals. Man-made noise, however, may also be beneficial to seals; there is anecdotal evidence of sea lions, and possibly other species of seals, apparently using the sound of a fishing boat's engines to locate the boat and take fish from the vessel's gear.

The Royal Commission concludes, therefore, that at present, underwater sound pollution has no widespread or continuing adverse effects on Canadian seal populations. However, sound pollution is one of the problems which may become more serious if there is a great increase in vessel traffic in the Arctic.

One other form of physical pollution of marine environments may be mentioned, but it is of no practical significance to seal populations. It is heat

pollution caused, for example, by the cooling water of thermal and nuclear power stations. The local effects of pollution of this kind are significant to many animals, but seals and other marine mammals are little affected, if at all, both because their wide-ranging habits enable them to avoid uncomfortable localities, and because they, like other warm-blooded animals, are able to tolerate much wider temperature ranges than are cold-blooded forms of animal life (Warren, 1971).

Chemical Pollution

During much of the present century humans have been pouring into the oceans vast quantities of substances, some of which never existed before, that in a variety of ways adversely affect the creatures living in the seas. The marine mammals, including the seals, have not been immune from these effects. Four groups of substances must be considered here because of their potential for harmful effects. These are radioactive substances, heavy metals and trace elements, petroleum compounds and organochlorine compounds.

Radioactive Substances

A variety of radio-isotopes has been entering the marine environment over the last 40 years, both as products of nuclear explosions and from other sources. Some of these radio-isotopes pass into the tissues of seals. Risebrough (1979) reports the presence of radioactive cesium and strontium in harp seals in the Gulf of St. Lawrence and of cesium in unspecified seals from the Northwest Territories. He states that the values found may be considered low, although above background levels for the environments in which the species evolved. He concludes: "An increase in levels of marine radioactivity would most likely result e.g. in an increase in mutation rates in marine mammals, but would not necessarily increase genetic variability. It is not therefore viewed as a serious threat to marine mammal populations."

It appears, therefore, that the potential risks to seal populations from the present levels of radioactive pollutants in the marine environment are not of serious concern.

Heavy Metals and Trace Elements

Since about 1970, the presence of high levels of mercury in the flesh of long-lived carnivorous fish such as sharks and swordfish has raised prob-

lems related to human health. The possibility of toxic effects from mercury in seals and other fish-eating mammals has therefore come under consideration. A considerable number of analyses of the mercury content of seal tissues have been made (Risebrough, 1979), and a great range of values has been found, exceeding three orders of magnitude. It is now generally accepted, however, that for the most part the mercury is of natural origin (Bonner, 1982). This finding does not exclude the existence of some locally high concentrations of mercury of industrial origin, although local "hot spots" of natural mercury also occur. For instance, the liver of a bearded seal from the Northwest Territories, far from any artificial source of mercury, is recorded as containing the very high level of 420 parts per million of mercury which, presumably, must ultimately have been derived from a natural source (Risebrough, 1979). There is also good evidence that seals have physiological mechanisms which help to protect them against adverse effects from mercury they ingest. Mercury in fish is found in the highly toxic methylmercury form, but only a little of this form is found in seals. Most of the mercury found in seals is in relatively harmless forms (Bonner, 1982) in a complex that includes selenium and bromine (Risebrough, 1979).

High concentrations of cadmium have been found in the kidneys both of seals and of whales (Wageman and Muir, 1984), and nickel has been associated with stillbirths in seals (Hyvarinen and Sipila, 1984).

No evidence has been found that any other heavy metal or trace element has any adverse effects on seals under natural conditions (Risebrough, 1979).

Petroleum Compounds

Since the tanker *Torrey Canyon* went aground in 1967, the risks of environmental catastrophe following a massive oil spill have been well recognized. Seals, as inhabitants of coastal waters, are among the animals which might be subject to serious damage on such an occasion, and it is important to know how susceptible they would be to such effects. Three possible ways in which an oil spill might affect seals are identified by Risebrough (1979). These are oiling of the pelage, which has an adverse effect on insulation; poisoning by ingested oil; and long-term sublethal effects arising from accumulation of persistent compounds in the ecosystem.

A number of observations and experiments with seals that are dependent primarily on their blubber for insulation (i.e., hair seals such as

grey seals and harp seals) have led to the conclusion that oiling of the pelage has little serious effect on survival (Risebrough, 1979; Bonner, 1982; Hofman and Bonner, 1985). The risk, however, seems to be considerably greater for fur seals, whose insulation could be seriously damaged by oil. Risebrough (1979) quotes Gentry et al. (1976), who found that the heat flux through experimentally oiled pelts of northern fur seals increased by a factor of 2, and that the metabolic rate of experimentally oiled fur seals increased 1.5 times. Fortunately there has not yet been a serious oil spill in the vicinity of a fur seal colony.

A few experiments have been done on the effects of ingested oil by dosing ringed and harp seals with oil. Seals store injested oil in their blubber until it is metabolized, and there is some evidence that mobilizing this unique pathway to clear oil may lead to adreno-cortical imbalance, anorexia, lethargy and reduced ability to survive stress (Engelhardt, 1982, 1983; Geraci and Smith, 1976). In any case, oiling causes seals intense distress and at least temporary eye ulceration (Smith and Geraci, 1975). However, Bonner (1982) concludes that "oil contamination or ingestion in quantities that might reasonably be expected in the course of a spill is unlikely to be irreversibly harmful to a healthy seal population."

In general, the Royal Commission accepts Bonner's conclusion, but the Commissioners believe that, if by some misfortune a major oil spill occurred in an area where northern fur seals were concentrated, serious immediate damage could be done through deaths of animals with contaminated pelage even though in the long term this damage might prove reversible and the population might recover to the level allowed by other environmental factors.

Ringed seals, too, may be particularly susceptible to the effects of an oil spill because of the conditions under which they live. Although they are known to avoid oil slicks when possible (Engelhardt, 1983; Smith and Geraci, 1975), these seals, when wintering in the sea ice, would be vulnerable because of their dependence for respiration on a few small breathing holes, leads and cracks. The toxic aromatic fractions of crude oil persist in arctic cold, and may accumulate along these ice edges (Engelhardt, 1983).

The Royal Commission did not find any useful studies on the question of whether long-term environmental degradation following a catastrophic or low-level continuing oil spill could adversely affect seal populations.

Organochlorine Compounds

Since the Second World War, organochlorine compounds, which never existed in nature, have become widely distributed through both the marine and the terrestrial environments with devastating effects on many biological communities. The substances of greatest concern are DDT and its derivatives, which are used primarily as insecticides, and polychlorinated biphenyls (PCBs), which have a great variety of industrial uses. By 1964, DDT had been detected in crabeater and Weddell seals in the Antarctic, although in fairly low concentrations (Risebrough, 1979). There are no parts of the world's oceans which are now entirely free of these compounds, although there are only a few areas where their concentrations are high enough to cause serious effects on seals. None of these areas is in Canadian waters, although one, Puget Sound, is closely adjacent. The occurrence of birth defects and pup mortality in harbour seals in this area, possibly as a result of relatively high levels of DDT and PCBs (Risebrough, 1979), has been noted in the material relating to the status of the harbour seal. (See Chapter 22.)

Other areas in which there are strong indications that organochlorine compounds have contributed to decline or mortalities in seal populations are San Francisco Bay (harbour seals), southern California (California sea lions), the Baltic Sea (ringed seals and grey seals), the Netherlands and West German coasts (harbour seals), and the Farallon Islands (Steller sea lions) (Risebrough, 1979). The effects operate generally through the reproductive system, and the chief results are prematurely born pups, which invariably die; birth defects in pups; and pathological changes in the uterus. The particular results depend upon the species of seal and the locality. The phenomenon has been well studied among California sea lions of southern California, but even there it is not entirely clear how far, and in what way, DDT and PCBs contribute to the problem. Three possible mechanisms have been discussed (Risebrough, 1979):

- High levels of DDT derivatives, with or without a contribution from PCBs, disturb the biochemical mechanisms controlling pregnancy.

- DDT derivatives, with or without a contribution from PCBs, lower the resistance of the seals to two pathogens which cause premature birth.

- The pathogens alone, without contributions from DDT and PCBs, cause premature births.

It is evident that the situation is complex and that, while it is virtually certain that organochlorine compounds, when present above critical concentrations, may cause serious difficulties for the survival of seal populations, much remains to be discovered about the mechanisms involved.

The Royal Commission has seen recent reports (Anonymous, 1985) that the deaths of a number of belugas in the St. Lawrence River are believed to be the result of poisoning with PCBs, DDT and another organochlorine insecticide (Mirex). Very large amounts of these chemicals are reported to have been found in the blubber and milk of the belugas. (These chemicals accumulate in the fat of animals.) No reports of dead seals are mentioned, but the mortality occurred near the mouth of the Saguenay River, which Sergeant (1973) identifies as a feeding area for adult harp seals. The Royal Commission is concerned, therefore, about the potential effects of the pollutants in this area on the harp seal population.

As noted above, only a few localities have been found where organochlorine compounds seem to be seriously affecting seal populations, and none of these is in Canada. Fortunately, there is reason to believe that in the long term this problem will diminish rather than increase. The use of DDT has greatly declined since the 1960s, when the world became aware of the threat that it was posing to many kinds of wildlife. PCB manufacture has declined rapidly since about 1970, although the environmental impact of this chemical may not have been reduced until much later (Addison et al., 1984). Addison et al. (1984) compared DDT and PCB concentrations in grey seals from Sable Island in 1974, 1976 and 1982; and in harp seals from the Gulf of St. Lawrence in 1971 and 1982. They concluded that their data "show convincingly that concentrations of the DDT group of insecticides in eastern Canadian seals have declined appreciably during the 1970s but that PCB concentrations have fallen much less, if at all." The differences in the trends of DDT and PCB compounds may be partly the result of a greater decline in recent years in environmental concentrations of DDT than of PCBs, and partly to some ability of seals to degrade and eliminate DDT compounds, but not PCBs. In the Bering Sea, however, Calambokidis and Peard (1985) found that DDT levels in northern fur seals on the Pribilof Islands in 1980 were at about the same levels as had been observed in 1968 and 1969; they were unable to rule out the possibility that some increase had occurred. While PCBs were measured in 1980, no comparable data for 1969 are available for comparison. Calambokidis and Peard (1985) note that the levels of PCBs and DDE (the main DDT derivative) were well below the levels detected in other pinnipeds showing reproductive dysfunctions.

Pollution with Plastic Debris

Concern about the great quantities of plastic material of diverse kinds which is now adrift in the oceans has been growing since the early 1970s. It particularly relates to the adverse effects on many species of marine animals, including both commercially important fish and species of significant public interest such as seabirds, turtles and endangered marine mammals. Plastic debris has also directly threatened human life when ships have had their intakes blocked or their propellers fouled (Hammond, 1984), or when divers have become entangled in it.

As one result of this concern the U.S. government organized a scientific workshop to examine the problem and discuss possible actions; this workshop was held in Honolulu in November 1984 (Anonymous, 1984). It dealt with the kinds and amounts of debris entering the oceans, its fate, the effect on marine resources, and actions which could be taken to mitigate the problems. Scientists from a number of other countries besides the United States were present. Interest was concentrated mainly on the Pacific Basin and particularly the north Pacific Ocean, although data from some other areas were also presented. The following summary has been drawn largely from the material presented at this workshop.

The Amount of Debris

The amounts of plastic material entering the ocean annually are very great; most of this material comes from fishing operations and from waste discarded by merchant ships. It also includes small plastic granules which may be of industrial origin, but this material is of much less significance to seals than it is to other marine animals, especially seabirds.

A recent estimate is that 145,000 pieces of netting, large and small, are lost or deliberately discarded annually in the Bering Sea alone (Wallace, 1984). This figure does not seem surprising when it is compared with the 15,000 miles of gill nets (Wallace, 1984) which are set daily in the north Pacific Ocean and with an average fishing effort by large trawlers in the Bering Sea–Gulf of Alaska area of over 2,000 vessel-months annually (Low et al., 1984). Another estimate is that in the whole world 350 million pounds of material are discarded or lost annually by the fishing fleet (Wallace, 1984). No data seem to be available at present relating to the amount of plastic debris originating from the fishing industry in the other area of direct concern to Canada, the northwest Atlantic Ocean; however, little informa-

tion has come before the Royal Commission to suggest that seals in this area are being adversely affected by entanglement to any significant extent.

The limited amount of data available in the matter of the amount of plastic material that is discarded by merchant ships suggests that, for the world as a whole, it is probably of about the same order as that produced by the fishing industry. In the north Pacific area, however, it is likely to be much less when the relative distributions of the two activities are compared. Further, the kinds of material which most frequently entangle seals are netting scraps, pieces of line and packing bands, and the first two of these are derived almost entirely from the fishing fleets.

It is true, of course, that other objects which have been found entangling seals, such as canned drink packs, may well come from any kind of vessels. It seems likely, however, that seabirds and some other marine animals may be relatively more vulnerable to debris of non-fishing origin than are the seals.

The Fate of Debris

Although it is the non-biodegradable nature of plastic materials that has given rise to the existing problem, the material does actually disappear gradually, and there is no occasion to fear an infinite build-up of plastic debris in the oceans as more is added each year and none is removed. Much of this material is washed ashore, where it may be buried naturally or can be removed by humans. Thus, if the amount of material entering the sea can be reduced, the quantity of drifting material and its harmful effects should also decline. On Amchitka Island in the Aleutians, for example, between 1974 and 1982, there was a decrease of 37% in the weight of trawl netting coming ashore (Merrell, 1984). This decrease is attributed to a reduction in the number of boats fishing off the area.

The amount of debris coming ashore on particular stretches of coast can vary greatly from place to place, even within a limited area depending, apparently, on local currents, and wind and wave effects. At sea, there is evidence that debris tends to be most abundant in certain areas, again as the result of the concentrating effect of the oceanic circulatory system.

Effects on Seals

There is substantial evidence that plastic debris has caused serious mortality in juvenile northern fur seals in the Bering Sea. This has been discussed in detail in Chapter 22.

Instances of entanglement in pieces of netting and other plastic debris have been observed in a number of other seal populations, but no other studies seem to have been undertaken to relate this entanglement to population structure and change in abundance. However, Dr. G. Stander (1985), Director of the Sea Fisheries Research Institute, Cape Town, South Africa provided the Royal Commission with an interesting set of data for the Cape fur seal. These data enable a comparison to be made between the proportion of animals observed to be entangled and the estimated rate at which the colony is increasing for a series of fur seal colonies along the South African coast. At first sight this comparison reveals a tendency for the rate of increase to be highest where the proportion entangled is lowest and vice versa. The correlation is not significant when tested by a Spearman rank test and, more important, the data themselves contain uncertainties. Some of the samples on which entanglement rates are based are small, and the Royal Commission has been advised that further modelling studies may change the estimated relative growth rates of some of the colonies. It appears, therefore, that these data, while not inconsistent with the hypothesis that entanglement contributes to seal mortality, cannot be regarded as giving the theory any definite support.

Entanglement in fishing gear – netting scraps and lines – has been observed in sea lions, northern elephant seals and harbour seals on the U.S. west coast. In the largest series of observations that the Royal Commission has found, samples of 13,000 sea lions and 11,000 northern elephant seals on the southern California coast both recorded 0.08% animals entangled (Stewart and Yochem, 1984). This figure is well below the observed figures for northern fur seals in the Bering Sea (0.4%) (Scordino, 1984) and probably reflects a lower intensity of commercial fishing in the area.

Other species which have been recorded as entangled are the Hawaiian monk seal (Henderson, 1984), the South American sea lion off Argentina (Wallace, 1984), the New Zealand fur seal off New Zealand (Cawthorn, 1984), and the Steller sea lion off Alaska (Calkins, 1984).

Entanglement can apparently cause the death of seals and other marine mammals in at least three ways, depending on the size of the netting fragment. Large pieces may cause the animal to drown; medium-sized

pieces may cause death from exhaustion and starvation as a result of the drag; and small fragments, if they form a loop round the animal, may cut through the tissues, particularly as a young animal grows, and cause lethal injuries (Wallace, 1984). There is abundant evidence, however, that many animals which have been entangled escape, sometimes quite quickly and without experiencing lasting harm. This evidence has been taken both from direct observation of individual identifiable animals (Scordino, 1984) and from the numerous records of animals bearing scars caused by previous entanglement.

Ameliorative Measures

Although there are indications that the amount of plastic debris in the sea may be decreasing in some areas (e.g., Merrell, 1984), the effects on seals and other marine animals are so serious that consideration must be given to introducing more specific measures to alleviate the problem. This might be achieved in the long term by a combination of deliberate efforts to reduce the amount of such material that is discarded and technological changes aimed at reducing the biological threat from material that does go adrift.

The Honolulu workshop pointed out that if the amount of material discarded were to be reduced, there was a need not only for appropriate regulatory measures, but also for educational campaigns aimed at informing the crews of merchant and fishing vessels, and the general public as well, about the damage caused by plastic debris and the importance of taking whatever steps are possible to minimize it.

The fishing industry is not only a major source of the problem but is also directly affected by its consequences. It should therefore be particularly involved in steps to improve the situation.

The simplest and most important of these steps would be to reduce the throwing overboard of plastic debris of all kinds, but particularly of netting fragments, damaged nets, plastic wrapping bands and ropes. The workshop pointed out, too, that a simple procedure like cutting packing bands before discarding them could save an animal's life, since the band could no longer encircle it.

Technological advances may be possible through development of the use of biodegradable materials in fishing gear so that lost and discarded fragments will ultimately break up and cease to be a threat to marine life.

There is likely to be difficulty, however, in achieving this advance without imposing additional costs on the industry. The possibilities of further recycling net material may also merit investigation (Anonymous, 1984).

Further, there is need for much more research to provide a basis for effective measures to mitigate the effects of plastic debris. Among the problems which should be addressed are:

- more detailed assessment of the impact on seals, fish, seabirds and turtles;
- determination of the sources and distribution of debris;
- determination of the fate of this material once it enters the marine environment; and
- development of means of identifying the origins of debris found in the sea and on shore.

Potential Effects of Arctic Development

The Arctic is, without doubt, the area in which the existing possibilities of development constitute the most serious threat to the seal populations and the people dependent on them. The ringed seal is the species whose future gives rise to the greatest concern, both because of its abundance and significance to the subsistence of the Inuit, and because some features of its breeding behaviour make it particularly vulnerable.

The aspects of arctic development which seem most likely to give rise to threats to the seal populations are surface mining of minerals, petroleum exploitation and large-scale ship traffic through the ice to service either or both of the primary developments. Some effects of these developments on the hunting activities of the Inuit and on the availability of the seals to them are considered in Chapter 13. The present chapter deals with the direct effects on the seals themselves.

The Laurentian Shield extends into the Arctic as far north as Ellesmere Island, offering lead, zinc and iron prospects. A number of sites are already under lease, and there are operating lead-zinc mines on Bathurst Island and northern Baffin Island. Coal fields are being explored in the high Arctic, chiefly on Ellesmere Island. Shipping supplies and ore through Lan-

caster Sound and Baffin Bay ice could affect seals. In addition, any contamination of surface waters with the toxic heavy metals commonly associated with lead-zinc ores would eventually enter the sea and could adversely affect the seals in ways mentioned earlier in this chapter.

Petroleum exploitation appears to pose a relatively minor direct threat to the seal populations of the Arctic. However, much of the area now being explored for oil and gas lies quite close to grounds traditionally hunted by the Inuit for ringed seals (see Figure 13.4, Chapter 13), and any serious spill could have an adverse effect, even if temporarily, on the level of seal populations.

Ship transport associated with petroleum or mineral development might well constitute a greater threat to the seals than the direct risks from spills. Ice-breakers may crush ringed seals in their birthing lairs under the snow and propagate wider ice displacements, affecting habitat conditions (Boles et al., 1983; Mansfield, 1983). Full development of the Sverdrup field could involve a fleet of more than 50 tankers, with a transit of Lancaster Sound every five to 10 hours, depending on time of year (Mansfield, 1983). Based on estimates of the density of lairs in relatively stable offshore ice (e.g., Alliston and MacLaren, 1981; Finley, 1978) and the fact that ringed seals quickly colonize ice-breaker tracks, it appears that thousands of seal lairs could be crushed each season. Ringed seal pups in lairs may be particularly susceptible to such impacts.

Engine noise would be nearly continuous if a 50-vessel tanker fleet were operating. It could mask seals' vocalizations and reduce the distances over which they could communicate (Mansfield, 1983; Terhune et al., 1979; Terhune and Ronald, 1975). Ringed seals do not appear to disperse when ice-breakers pass because their winter mobility is extremely limited (Alliston, 1980, 1981), but they may eventually abandon persistently noisy areas (Freeman, 1976; Mansfield, 1980, 1983; Boles et al., 1983; Smith and Hammill, 1981; Labrador Inuit Association, 1985).

The potential effects on seals of any form of arctic development, particularly if it involves large-scale ship transport through the ice, appear to be sufficiently serious to make it important that they should be carefully examined before any decision is taken to permit development.

In the Atlantic region, there does not seem to be the same degree of concern about the potential impacts on seals from offshore oil and gas exploration and exploitation. This is because the seals in question are hair

seals and, as stated earlier, oiling of the pelage of these species has little serious effect on their survival. As well, the species found in this region do not maintain breathing holes in ice, and therefore, the potential impacts of ice-breaker traffic and oil contamination on breathing holes do not arise.

Conclusions

1. Reduction in the abundance of fish by commercial fisheries may possibly have an adverse effect on seal populations in some situations, but no such cases have been clearly identified either for seals or for other marine mammals.

2. Where commercial fisheries take fish which prey either directly on seals or on smaller fish which are eaten by seals, the impact of the fishery may actually be beneficial to the seal population.

3. Some seals are killed by becoming entangled in fishing gear either accidentally or when trying to take fish from the gear. There are no Canadian estimates of the numbers of seals dying in this way, but the limited evidence suggests that they are small compared either to some past commercial kills (harp seals) or the natural rate of increase of some populations (harp seals and grey seals).

4. There is no evidence that underwater sound pollution such as that from ships' engines or seismic sounding has at present any continuing or widespread effects on Canadian seal populations. However, if large-scale ship transport develops in the Arctic, the noise may tend to drive the seals away from the areas affected.

5. Radioactive pollution does not seem to be a serious threat to Canadian seal populations.

6. Any mercury occurring in seals in significant quantities is of natural origin, and no other heavy metals have adverse effects on seals under natural conditions.

7. The principal danger to seals in the event of a major oil spill in an area they inhabit would be to northern fur seals as a result of loss of thermal insulation because of oiling of the pelage. All other Canadian seals, which depend mainly on their blubber for insulation, seem to be much less vulnerable in this respect; however, ringed seals could be vulnerable if oil were to accumulate at their breathing holes.

8. Organochlorine compounds, mainly PCBs, and DDT and its derivatives, appear to have had serious effects on seal populations in a few areas such as the southern North Sea, southern California and Puget Sound. No evidence has been seen of significant effects on seals in Canadian waters, although organochlorine compounds appear to have killed belugas in an area of the St. Lawrence River where harp seals feed. Present indications are that the incidence of DDT is declining in some areas, but the picture for PCBs is less clear.

9. Plastic debris adrift in the oceans, particularly lost or discarded fishing nets and pieces of nets, causes the deaths of many seals, as well as the deaths of other marine mammals and birds. The most serious effects at present seem to be on the northern fur seal, and it is likely that they are the principal cause of the decline in this population since the 1960s. There is a need for active intervention to try to alleviate this problem.

10. Serious adverse effects on seals, particularly ringed seals, in the Arctic could result from development in the form of surface mining for minerals, oil/gas exploration and exploitation and, particularly, large-scale sea transport through the ice in association with these enterprises.

Recommendations

1. The Canadian government should work both domestically and internationally to reduce the amount of netting and other plastic material being discarded at sea. It should also support studies aimed at developing modifications to fishing gear which will reduce the hazard to seals and other marine life caused by the lost nets.

2. The Canadian government should not permit development in any part of the Arctic without a thorough investigation and disclosure of the potential environmental impacts on seals and sealing communities.

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PART V

Biological Issues

PART V b

Impacts of Seals on Fisheries

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V b Impacts of Seals on Fisheries

Chapter 24

Impact on Fish Stocks and Catches

> *. . . There is no reason to believe that the harp seal has had a serious impact on fish stocks and, therefore, fish catches, and that in fact harp seals play only a small part in competition with humans for preferred fish stocks (Hughes, 1985).*
>
> *Clearly, the seal population is growing . . . and seals have to eat. And they consume a lot of fish. They are not eating blueberries or anything that is available on land; they are eating fish (Chapman, 1985).*

Introduction

The Royal Commission's responsibilities on this topic derive from Paragraph 5 (d) and (e) of its terms of reference. These sections state:

- *the interactions between seals and commercially exploited fish populations that may affect food supplies* or contribute to parasite transmission;

- *the interaction between seal populations and commercial fisheries, including, inter alia, competition between seals and fishermen for fish stocks*; interference in fishing activity by seals, including damage to fishing gear and catches; and the effects and related economic costs on the quality of fish catches caused by transmission of parasites by seals. (Emphasis added.)

The Commission's primary concern on these matters is with the effects of predation by seals on the stocks of commercially exploited species; it is assumed that "fish" in this context includes invertebrate animals such as shrimps, which are of commercial importance, and "fish" will be used in this sense in the rest of this chapter. Of secondary concern are the effects of seal predation on species which interact with commercially important species. These effects are secondary in the sense that the effects produced by the seals on commercial stocks are indirect rather than direct; this statement should

not be taken to imply that the extent, and therefore the practical significance, of these effects will *necessarily* be less than the direct effects. There is not yet sufficient scientific information, either in the form of models relating the commercial fish stocks to other animals in their environment, or as data for use in these models, to make it possible to examine the secondary effects in a quantitative manner, although it is probably possible to predict the directions in which they will operate. This chapter, therefore, will deal principally with the primary effects of seals on fish stocks and seek answers to the following questions:

- *What do seals eat?*
  The food of all species of seals consists exclusively of animals, both fish and invertebrates, although different species have different principal foods. This chapter seeks to establish the proportion of food formed by each of the important food animals, how this varies by season and locality as the seals undertake their annual migrations, and how the proportions change as the seals grow and mature.

- *How much do seals eat?*
  The basic question is how much food an individual seal needs to grow, maintain itself and carry out its feeding, migrating and other activities. Females need a substantial amount of extra food to support development of the young and milk production while pups are suckled; males also have increased energy requirements in the breeding season. We also need to know how the amount of food consumed varies seasonally, locally and as the animals grow. Combining this knowledge of the food requirements of individual seals with information on the size, composition and movements of the seal population as a whole provides an estimate of the total food consumption of the seal populations for which such data are available.

- *How much of the commercially important fish species do seals eat?*
  A response to this question can be formulated by combining the answers to the first two questions. If, for example, a given seal population consumed an estimated 10,000 tonnes (t) of food a year, and half their food *always* consisted of herring, it could be concluded that these seals ate 5,000 t of herring a year. Unfortunately, the answer to the question is not as simple in practice. Although there is some variation in the amount that individual seals eat, this is small compared to the variability in the species composition of their food. This variability depends primarily on the kinds of food available to the seals, which may change greatly with the season and from one area to another. To obtain an estimate of the amount of any particular fish or invertebrate consumed by

a given seal population, the data need to be subdivided as finely as possible, to take account of the amount and composition of the food eaten by particular components of the seal population at particular times. Unfortunately, the existing data of this kind are both patchy in nature and, even for the most studied species, barely adequate in quantity; for other species virtually no data exist.

- *What is the effect of the removals by seals on the stocks of commercial fish?*

- *How do these effects of seal predation on commercial fish stocks further influence the commercial catches?*
These two questions interlock so closely that they almost always have to be considered together. The size and structure of a fish population (the proportion of animals of different ages and the two sexes) depends on the number of young being produced by the parents in the previous generation, and on the rate at which the fish are dying off from a variety of causes such as fishing, predation by seals and other predators (birds, sharks, etc.), disease, and old age. If the number of fish killed by seals is reduced, perhaps because of a reduction in the number of seals, the average population will not be increased by an amount equal to the number "saved"; neither will all the saved fish subsequently be taken by the fishery. They will die off gradually, and their deaths will be distributed among all the other possible causes. The effect on the commercial catch will depend, in part, on the relative timing of the fishermen's and the seals' operations. If, for example, the seals had been taking all their share in a short period just before an intense fishery operation like some salmon gill-net fisheries, the fishery might catch most of the fish saved from the seals. If, however, the seals were taking larger fish than those taken in the commercial catch, stopping the seal take would have relatively little effect on the catch, since the fishermen have already had first chance. The extent to which any effects of seal predation on commercial catches that do occur can be detected in practice will also be influenced by the amount of natural variation in the abundance of the prey species. Some fish, such as capelin, show great variation in the number of young produced from year to year so that any effects on the catch resulting from changes in the numbers eaten by seals may well be masked.

A question closely related to those above concerns the effects which the reduction of fish stocks by commercial fisheries have on the well-being and abundance of the seal populations. This is considered in Chapters 21, 22 and 23, which deal with the status of seal stocks and human effects on those

stocks. However, the necessary basic information on seal diet and on the dynamics of fish and seal populations is the same, and it is worth remembering that interactions work in both directions.

These technical and biological questions, once answered, lead into the political question which is the basic reason for the Royal Commission's interest in this subject: should seal numbers be reduced, by a cull, for example, in order to benefit the commercial fisheries? This question is examined in Chapter 29, which takes into account other factors such as the transmission of parasites, gear damage, costs of a cull, and public attitudes towards a cull; the question will not be addressed directly here. The answers produced here to the final question asked above refer primarily to the impact of the overall consumption of fish by seals on commercial catches, and can, by dividing by the estimates of the total number of seals, be expressed as the average impact per seal. The more meaningful quantity in relation to management policy, however, is the marginal impact, that is, the change in commercial catches that would result from a given small change in seal numbers. As discussed in Chapter 29, this will not necessarily be the same as the average impact, but the calculations of total average impact provide an essential stage in the process of estimating the marginal impact.

What Do Seals Eat?

Biologists who have studied seals generally agree that they are opportunistic feeders. That is, they feed mainly on whatever animals are most abundant in the particular place and time where they are living. Their food consists mainly of small- and medium-sized fish, shrimp and other pelagic crustaceans, and squid. Only the bearded seal seems to feed largely on benthic invertebrates.

Most of the available data on the feeding habits of Canadian seals are examined in detail in Northridge (1986). The following sections summarize some of the published information about the feeding habits of the various species of seals. The available data on harp, hooded, harbour, grey and northern fur seals are summarized in tables for each species.

Harp Seal

In addition to the review in Northridge (1986), Bowen (1985) and Beddington and Williams (1979b) have provided comprehensive reviews of

the information about the composition of the food of harp seals. These reviews suggest that the feeding habits at each stage in the life history of harp seals can be summarized as follows:

- Pups (whitecoats), born in early March in the Gulf of St. Lawrence and northeast of Newfoundland, are dependent on milk; they moult and become beaters at about three weeks of age.

- Beaters fast for a period of two to three weeks while they live on the fat accumulated while suckling, and generally start feeding in late April. They then migrate north along the Newfoundland coast, feeding mainly on shrimps including the commercially important *Pandalus borealis* and euphausiids, although they also take small quantities of fish.

- During the summer, beaters and immatures (one to five years of age) live mainly off the coast of west Greenland. There they feed heavily on small crustaceans and to a lesser extent on small fish, predominantly capelin. There are regional and seasonal variations; in some years arctic cod are an important part of the food of harp seals. Immatures may take a higher proportion of capelin than do beaters.

- Capelin appears to be a major food during both the northward spring migration and the southward autumn migration along the coast of Labrador, but the number of observations is extremely limited. A variety of other species of fish are eaten. Arctic cod, not to be confused with the commercially important Atlantic cod, may be particularly important in the autumn.

- In the Gulf of St. Lawrence juveniles and older seals feed mainly on capelin during the winter, but also on other pelagic fish and crustaceans, as well as arctic cod on occasions. Records indicate that herring are taken around the Magdalen Islands in the spring (Fisher and Mackenzie, 1955; Myers, 1959).

Northridge (1986) has pointed out, however, that all these conclusions are based on only about five small samples of harp seal stomach contents, and that a single sample obtained from a group of seals, all of which are feeding on a particular prey, may lead to an overestimate of a particular prey species. Table 24.1 summarizes the published data on the stomach contents of harp seals, and examination suggests that these support only the more limited conclusions that:

- Capelin is one of the major foods of harp seals throughout their range.

Table 24.1
Summary of Feeding Data for Harp Seals

Food Species	No. of Stomachs Containing Item	Minimum No. of Samples	% of Occurrences[a]
"Winter": December through June (total 1579 + "several" stomachs)			
Flatfish (all species)	30.5	4	5.5
Witch	2.0	1	–
Plaice	1.0	1	–
Cod	4.0	3	0.7
Redfish	4.0	2	0.7
Capelin	205.5	15	37.0
Herring	196.0	8	35.3
Barracudina	1.5	1	–
Skate	1.0	1	–
Decapods (indet. spp.)	64.0	7	11.5
Pandalus spp.	12.5[b]	3	2.2
Euphausiids	24.5	8	4.4
Squid	2.5	2	–
Octopus	0.5	1	–
Unidentified	27.0	2	4.8
Empty	1,024.0	21	–
"Summer": July through November (total numbers of stomachs unknown)			
Arctic cod	12+	6	c
Capelin	Often recorded	5	c
Mysids	9	5	c
Euphausiids	5	2	c
Amphipods	7	3	c

Source: Compiled by Northridge (1986) from data from Dunbar (1949), Myers (1959), Fisher and Mackenzie (1955), Sergeant (1973, 1976), and Stewart and Lavigne (1980, cited in Bowen, 1981).

a. For 555 winter samples, excluding empty stomachs.
b. Plus "several".
c. Unquantifiable.

- Herring is an important food when its migrations coincide with those of the harp seals, as occurs near the Magdalen Islands in the spring.

- Crustaceans, including commercial species of shrimp, are consumed by harp seals in significant quantities, both in the Gulf. of St. Lawrence and in northern waters.

- Other commercial fish, particularly flatfish, form a small, but not negligible, part of the food in the southern (winter) range.

Attempts to specify the proportion of the diet of harp seals which are made up of particular species or groups can only be tentative and have wide ranges of possible values.

Hooded Seal

Comparatively little is known about the feeding habits of the hooded seal in Canadian waters. It generally inhabits deeper water than harp seals and is believed to dive deeper. Sergeant (1979) reports that its food includes squid, redfish, Greenland halibut, capelin and arctic cod. Pups may eat small crustacea. More data are available for Greenland, and Table 24.2 summarizes some results. Of the stomachs which were not empty, the great majority (87%–100%) contained fish, and only a very small proportion contained squid, shrimp and other crustacea. Most of the fish were large commercial species such as Greenland halibut, redfish, gadids (e.g., cod), and wolffish. Capelin were found in about 4% of the stomachs.

Harbour Seal

The harbour seal is widespread, found in cool temperature waters of all northern hemisphere oceans and in the eastern Canadian Arctic. It is generally non-migratory and lives in small localized populations with probably little mixing among them. Bonner (1979) states that it feeds on "pelagic, demersal, anadromic and catadromic fishes, cephalopods and crustacea. Gadids, clupeids, pleuronectids and salmonids are fishes of commercial importance eaten by these seals."

Spalding (1964) reported on the food of harbour seals off the west coast of Canada. He found a large number of species, mainly fish, in the stomachs of the 50 harbour seals sampled. The most frequent were salmon, octopus, squid, clupeids (herring), and rockfish. (In this chapter, the term

Table 24.2
Stomach Contents of Hooded Seals Caught in Greenland Waters 1970–1978

Stomach Contents	South Greenland 1970–78		Southeast Greenland 1970–74		Northwest Greenland 1972–78	
	No.	%	No.	%	No.	%
Fish						
Greenland halibut	13	1.0	2	0.9	278	45.3
Wolffish	28	2.3	1	0.4	49	8.0
Redfish	101	8.2	24	10.2	6	1.0
Capelin	58	4.7	1	0.4	26	4.2
Gadidae	131	10.6	1	0.4	15	2.4
Other fish	15	1.2	–	–	22	3.6
Unspecified	482	39.0	1	0.4	5	0.8
Fish total	828	67.0	30	12.7	401	65.3
Squid	6	0.5	–	–	1	0.2
Crustaceans						
Decapods	14	1.1	–	–	4	0.6
Other crustaceans	2	0.2	–	–	55	9.0
Crustacean total	16	1.3	–	–	59	9.6
Stomachs with food	850	68.8	30	12.7	461	75.1
Stomachs empty	386	31.2	206	87.3	153	24.9
Total of records	1,236	100.0	236	100.0	614	100.0

Source: Kapel (1982).

"salmon" when relating to the west coast of Canada, refers to sockeye, pink, coho, chinook and chum salmon, and sometimes the steelhead trout.) About 54% of the food was fish of commercial value, including herring, salmon, eulachon, hake, whiting, flatfish, sablefish and lingcod. Salmon and herring were the most common commercial species. Salmon was found in about 23% of the seals examined, and herring in about 11%. Unfortunately, it is not clear whether these figures refer to the percentages, by weight or volume, of the various foods in the stomachs examined, or to the percentages of seals which contained each prey. The figures probably overestimate the amount of

salmon and underestimate the amount of herring, as 88% of the samples were taken between June and October, when salmon are returning to the rivers. Herring are available to the seals mainly in winter.

Boulva and McLaren (1979) reported on the stomach contents of about 600 harbour seals in eastern Canada. In the half that contained food, the most common prey were herring (24%), squid (21%) and flounder (14%), but 14 other species of fish, crabs and molluscs were also found (Table 24.3). These percentages are described as occurrences, but appear from the text to be percentages of the total number of prey items. As in the western Canadian studies, most samples were taken in summer and autumn. It is not clear what effect this timing would have on the relation between the relative occurrence of the various fish species in the samples and in the total consumption. The data of Boulva and McLaren include 201 stomach contents from the Atlantic coast which were originally reported by Fisher and Mackenzie (1955). In this sample the percentages by volume of the most frequent foods were herring (37%), winter flounder (13%), hake (8%), gaspereau and squid (each 7%).

It is evident that the harbour seal is an opportunistic feeder, varying its diet from time to time and place to place according to local abundance and availability of the species on which it feeds. In these circumstances, it is not possible to make any useful generalizations concerning the proportion of its total food which is composed of any particular prey species, but it is evident that in most areas much of its food will consist of common pelagic and demersal (bottom-dwelling) fish which are also of interest to commercial fishermen.

Grey Seal

The grey seal is common on the west coast of Europe, as well as on the east coast of Canada, and it has been studied quite extensively in Europe because of the damage it is reputed to do to the salmon fishery. The most recent review of Canadian data on the food of grey seals is by Mansfield and Beck (1977), who incorporated material used by Fisher and Mackenzie (1955). Their tabulation of the results of the examination of 446 stomachs, of which 207 contained food, is reproduced in Table 24.4. These data relate only to frequency of occurrence. The average number of species found in a single seal stomach is approximately 1.5, so that it appears that few seals would contain more than one or two prey species at one time. The data give no direct information on the quantities of the various species present in the stomachs, although the small number of species per stomach may imply a

Table 24.3
Summary of Atlantic Data on Harbour Seal Feeding

Food Species	Fisher and Mackenzie (201 stomachs)		Boulva and McLaren (279 stomachs[a])
	No. of Stomachs	% of Volume	% of Occurrence
Smelt	7	2	3.7
Shad	2	2	0.8
Gaspereau (Alewife)	5	7	6.8
Winter flounder	37	13	–
Smooth flounder	3	trace	–
Unidentified flatfish	14	5	14.1
Cod family	13	2	–
Cod	–	–	2.1
Haddock	10	2	1.8
Pollock	–	–	1.1
Hake	28	8	6.0
Ocean pout	–	–	0.7
Wolffish	–	–	0.6
Sand lance	–	–	2.9
Redfish (Rosefish)	4	1	1.9
Sea raven	–	–	0.6
Cunner	–	–	0.9
Morone	–	–	0.4
Capelin	–	–	2.9
Herring	64	37	24.2
Mackerel	–	–	3.6
Selachian egg cases	–	–	0.8
Crab	–	–	1.0
Shrimp	7	1	2.2
Limpet, Scallop & Clam	–	–	0.3
Squid	82	7	20.6
Unidentified fish meat (not herring)	42	13	–
Empty	87	–	–

Source: Fisher and Mackenzie (1955), Boulva and McLaren (1979).

a. Containing food.

Table 24.4
Food Items from 446 Grey Seal Stomachs Sampled in Atlantic Canada

	Species	No. of Times Occurring	Percentage Occurrence
	Fish		
*	Herring, *Clupea harengus*	48	15.9
*	Cod, *Gadus* spp.	35	11.6
*	Flounder, Pleuronectidae	30	9.9
*	Skate, Rajidae	29	9.6
*	Mackerel, *Scomber scombrus*	15	5.0
*	Hake, *Merluccius* spp. and *Urophycis* spp.	8	2.6
*	Salmon, *Salmo salar*	5	1.7
*	Smelt, *Osmerus mordax*	4	1.3
*	Shad, *Alosa sapidissima*	4	1.3
*	Lumpfish, Cyclopteridae	4	1.3
	Sand lance, *Ammodytes* spp.	3	1.0
	Skate egg case, Rajidae	3	1.0
	Cunner, *Tautogolabrus adspersus*	2	0.7
*	Capelin, *Mallotus villosus*	2	0.7
	Sculpin, Cottidae	2	0.7
*	Wolffish, *Anarhichas* spp.	2	0.7
*	Salmon eggs, Salmonidae	1	0.3
*	Haddock, *Melanogrammus aeglefinus*	1	0.3
*	Pollock, *Pollachius virens*	1	0.3
	Prickleback, Stichaeidae	1	0.3
	Dogfish, Squalidae	1	0.3
	Unidentified fish	43	14.2
	Invertebrates		
*	Squid, unidentified spp.	17	5.6
*	Shrimp, unidentified spp.	8	2.6
*	Rock crab, *Cancer* spp.	7	2.3
	Gastropoda	4	1.3
	Clam, unidentified spp.	3	1.0
	Polychaeta	3	1.0
	Sipunculida	2	0.7
*	Lobster, *Homarus americanus*	1	0.3
	Spider crab, Maiidae	1	0.3
*	Mussel, Mytilidae	1	0.3
	Seaweed, algae	6	2.0
	Mud, clay, stones	5	1.7
	Empty	239	

Source: Mansfield and Beck (1977).

* Of commercial importance.

fairly close relationship between frequency of occurrence and quantities eaten, at least for the more important prey species. Concerning the occurrence of flounders in the table, Mansfield and Beck (1977) note that this term includes at least seven species; the two most commercially important species, plaice and witch, were not found in 11 stomachs from the Magdalen Islands, and the species most frequently recorded was winter flounder, which is of minor commercial importance. The number of species consumed by grey seals is considerable, but in this sample, five species of fish (herring, cod, flounder, skate and mackerel) contribute over 50% of the occurrences. The species marked with an asterisk are those of some commercial importance, and it is evident that they constitute a very large proportion of the food of at least this sample of Canadian grey seals.

More data on the food of the grey seal are available from the eastern Atlantic. Table 24.5 summarizes the results of studies of the food of the grey seal at four localities round the British Isles (SMRU, 1985) and round Iceland (Hauksson, 1984). These data clearly illustrate two points. The first is that,

Table 24.5
Percentage Composition of Food of Grey Seals in Eastern Canada, at Four British Localities, and at Iceland

	Eastern Canada	Donna Nook	Farne Islands	Isle of May	Orkney Islands	Iceland
Demersal[a]	49.8	63.9	65.0	82.2	18.8	66.1
Pelagic[b]	37.2	0.6	–	–	–	5.7
Sand lance	1.0	28.7	32.9	14.9	80.4	5.4
Others	13.0	6.8	2.0	2.9	0.8	22.8

Source: Canada: Mansfield and Beck (1977). United Kingdom: SMRU (1985). Iceland: Hauksson (1984).

a. The principal demersal species in the British Isles and Iceland are cod, flatfishes, whiting, saithe and haddock.

b. The principal pelagic species in the British Isles and Iceland are herring and mackerel.

in many cases, a large proportion of the food of grey seals consists of commercially exploited demersal fish species; the total range is 19%–82%, but the low figure applies to an area where sand eels (sand lance) are clearly abundant, and in the other four areas the range is 64%–82%. The second point that the data illustrate is the great variability from place to place in the composition of the food. The Canadian data are also summarized in Table 24.5. While the total proportion of commercially important species (demersal and pelagic) is again very large (87%), the data include a higher proportion of pelagic species than do the data for grey seals taken in European waters (37%).

Northern Fur Seal

This seal is confined to the north Pacific Ocean and the Bering Sea. Because of its commercial value and the fact that its management was under the control of the North Pacific Fur Seal Commission, it has been studied extensively. It feeds on a wide variety of pelagic fishes and squids. Kajimura (1984) recorded 63 species in stomach samples. Like most seals, it appears to be an opportunistic feeder, and its principal prey varies greatly with time and season (Lander and Kajimura, 1982). Fur seals migrate south from their breeding grounds in the Bering Sea and appear off the B. C. coast only during the winter and spring (December–June). Spalding (1964) reported on the stomach contents of over 2,000 fur seals taken in B. C. waters. Herring was the dominant food found, making up nearly 50% of the total; of the remainder, squid was the most important (20%). Salmon accounted for less than 10%.

Perez and Bigg (1985) examined over 18,000 fur seal stomachs taken at sea throughout the species' range. Like Spalding, they found that herring was the dominant food on the B.C. coast, making up 43% by volume of stomach contents, weighted by calorific value. Squid and salmon each made up about 20% of the weighted volume; most of the salmon was found in seals taken offshore. A number of fish species of commercial importance, including pollock, Pacific cod, whiting and sablefish were also found in smaller amounts (up to 5%). Table 24.6 lists the principal species found in the stomachs of fur seals by Perez and Bigg (1985); those of importance off British Columbia are marked with an asterisk.

Table 24.6
Food Composition from Stomachs of Northern Fur Seals[a]

	Prey	Number of Occurrences as the Only Food Item	Percent
	Pacific sand lance	517	84.5
*	Pacific herring	686	69.3
	Walleye pollock	401	68.7
	Threespine stickleback	65	68.4
	Northern anchovy	771	66.8
	Capelin	708	66.7
	Rockfishes	210	61.8
*	Salmonids	228	50.2
	Pacific whiting	296	48.9
	American shad	32	47.1
*	Eulachon	50	44.2
	Onychoteuthid squids	164	41.1
	Atka mackerel	54	39.7
	Jack mackerel	27	36.5
	Flounders	23	32.5
*	Sablefish	40	30.8
*	Market squid	83	26.3
	Pacific saury	86	26.0
	Myctophiform fishes	15	21.1
	Gonatopsis borealis (squid)	121	21.1
*	*Berryteuthis magister* (squid)	98	20.2

Sources: Perez and Bigg (1985, Table 2).

a. Percentage of the total number of occurrences of each important prey species (N > 50) in which the food item was the only food item found in stomachs of northern fur seals.

* Of commercial importance in B.C. waters.

Sea Lions

Two species of sea lions are found on the Canadian west coast. The population centre of the California sea lion is on the southern U.S. west coast, but about 4,500 males enter Canadian waters, mainly in fall and winter; 5,000 to 6,000 Steller sea lions inhabit Canadian territory throughout the year.

Spalding (1964) reported on the stomach contents of 393 Steller sea lions taken off the B.C. coast. Like the harbour seal, this sea lion feeds mainly inshore, and the broad range of food found in the stomachs of the two species is similar. The dominant food of Steller sea lions appears to be octopus (20%). A variety of commercial fish accounted for just over 50%, including herring (10%), salmon (6%), hake and several other species. The percentage of commercially important species eaten depends on what is available at the time and place where the sea lions are feeding. Sixteen in a sample of 29 Steller sea lions collected in Barkley Sound on the lower B.C. coast, a herring spawning area, contained herring in their stomachs. The small proportion of salmon that Spalding reported may not represent the extent to which sea lions eat salmon, since few of his samples were taken during the period of the principal salmon runs through inshore waters. Three out of a sample of four taken in July and August, when salmon were running, contained salmon.

Dr. M.A. Bigg (1985) provided data on the composition of the food of Steller sea lions along the B.C. coast during fall and winter, obtained by examination of scats at hauling-out places. Roughly 50% of the food consisted of herring, with the remainder comprising approximately equal amounts of dogfish, hake, salmon, eulachon and squid. Other species such as pollock, anchovy, skate and rockfish occurred in minor amounts. There are major variations, however, in the food consumption from place to place and time to time, depending on the movements of other prey species, particularly salmon and herring.

The combined observations of Spalding (summer) and of Bigg (winter) suggest that herring could make up about 30% of the diet of Steller sea lions.

Bigg also advised that visiting California sea lions ate essentially the same foods as Steller sea lions in winter.

Northern Elephant Seal

The numbers of northern elephant seals visiting the B.C. coast are probably too small to have any impact on commercial fish stocks. Le Boeuf (1979) states that it "feeds near shore and offshore to a depth of 100 fathoms . . . species include bottom and mid-water fishes, skates, rays, ratfish, small sharks, squid, Pacific hake."

Bearded Seal

The bearded seal is essentially an arctic species which lives in shallow water near the pack ice (Stirling and Archibald, 1979). As a result its feeding habits have no significant impact on commercial fisheries. Bearded seals eat a great variety of food in shallow water, including demersal fish and invertebrates (Davis et al., 1980).

Ringed Seal

The ringed seal is even more of an arctic species than the bearded seal, as it keeps open breathing holes in the ice during the winter and does not have to retreat southwards with the pack ice. Davis et al. (1980) reviewed data on its feeding habits and reported a great variety of both fish and invertebrates in ringed seal stomachs. Davis et al. quote Lowry et al. (1978) that "it appears that food consumed by ringed seals at any given place and time will consist of the most abundant and suitable species." Since there are no significant commercial fisheries within its area of distribution, it has no appreciable impact on catches.

The seal species which are likely to have sufficient potential impact on commercial fisheries to merit further discussion in this chapter are harp, hooded, harbour, grey and northern fur seals, and both species of sea lions.

How Much Do Seals Eat?

Although the kind of food a seal eats depends on the species of seal and on the kind of prey animals available at any particular place and time, the amount it eats in a day is much less variable. A seal, like any other animal, requires food to provide the necessary energy to maintain its bodily processes, to grow, to undertake activities such as swimming, fishing and

migrating, and in the case of females, to develop and suckle its young. The energy required, relative to size, varies little between species of seals, or indeed between seals and other mammals (Lavigne et al., 1985). Any differences probably result from differences in such factors as sexual activity, the amount of swimming the animals do, and the temperatures in which they normally live. Species such as northern fur seals and harp seals that make long migrations may spend more energy than localized species such as harbour seals. Animals living in cold water, such as bearded and ringed seals, and harp and northern fur seals at the northern end of their migrations, may need more energy to maintain their body temperatures than more southern-dwelling species such as harbour and grey seals. Young seals of all species are still growing rapidly and need more energy than older animals which only have to maintain a steady body weight. Actively breeding males (Anderson and Fedak, 1985) and female seals which are pregnant or suckling young (Fedak and Anderson, 1982) need substantial amounts of additional energy over their normal individual requirements. None of the evidence seen by the Royal Commission suggests any other differences in the amounts of food consumed by different species of seals, except as a consequence of their size differences, as discussed later in this chapter. We shall therefore pool the available evidence on all species to develop an estimate of the amount of food consumed by seals of any species.

The amount of food that individual seals eat in a day can be estimated in three ways:

- Measure the amount of food in the stomachs of wild seals when killed, and multiply this by the number of "meals" taken in a day.

- Find the amount of food required to keep captive seals healthy.

- Examine experimentally the amount of energy, measured in kilocalories (kcal), which seals and related animals require to maintain their activities, and determine the amount of food needed to provide this energy.

Each approach yields useful information, and the results of all three are reasonably consistent.

Stomach Contents and Rate of Digestion

Boulva and McLaren (1979) reported on the weight of the stomach contents of 25 harbour seals from eastern Canada. Despite great individual

variation, the average contents were about 4% of body weight in small seals and 3% in large seals. Boulva and McLaren fitted to their data the regression equation:

$$\text{food weight} = 0.089\,(\text{seal weight})^{0.76}\ .$$

Weights were in kilograms. As their studies also showed that the seals fed during the night and usually rested on shore during the day, they assumed that the average stomach contents of animals killed in the morning represented one daily meal. The above relation was apparently obtained by fitting a functional regression (Ricker, 1975) to their observed data. The fact that the value of the exponent (0.76) is the same as that commonly used to describe the relation between the basic metabolic energy requirement and body weight in many mammals seems to be coincidental, although somewhat similar values should be expected.

Sergeant (1973) records the highest percentage weight of food in the stomach of an unspecified sample of harp seals as 4.7% in both an adult and a young seal. He provides no evidence on frequency of feeding during the day. Spalding (1964) reports the maximum percentage weights of stomach contents found in harbour seals and northern fur seals as 11% and 10% respectively; in the Steller sea lion, a much larger animal, the maximum percentage found was 2%. The variability of the data and the uncertainty as to how accurately the average stomach contents represent daily food consumption make it difficult to estimate accurately the average daily food consumption in this way. Few data have been published on the variability of the stomach contents, but the root mean square of the deviation from regression of Boulva and McLaren's data is about 1.3% of body weight. The mean stomach contents are also likely to be an underestimate of daily food consumption unless the animals take all their food within a short time and are killed and examined immediately afterwards. Otherwise, food already digested or food that would have been eaten later in the daily cycle is not measured. Spalding (1964) found evidence that northern fur seals and Steller sea lions feed almost entirely at night, as do harbour seals (Boulva and McLaren, 1979). Spalding's report does not make clear, however, whether harbour seals on the west coast had similar feeding patterns.

Captive Seals

There are considerable data on the amounts of food supplied to captive seals. Boulva and McLaren (1979) collected information from a number of institutions where seals were kept in captivity, and they pointed out that

some captive seals are "obviously overfed", and that it is necessary to select institutions where the animals were given just enough food to "satisfy the needs of a moderately active seal". Using data from six facilities selected on this basis, they found feeding rates for harbour seals ranging between 2.6% and 5.5% of body weight per day, with a mean of 4.6%. They note that some seals were receiving less than the amount predicted by their regression formula, but on average they received 25% more. Spalding (1964) quotes Scheffer (1958) as recording daily diets for harbour seals of 6% of body weight. Havinga (1933) found that the average stomach contents of adult harbour seals weighing about 100 kilograms was about five kilograms; his experiments with marked food indicated that this represented the daily intake. He also found that the rate of intake of 5% of body weight a day was consistent with observations of captive animals.

Some data are also available for other species of seals. Geraci (1972) found that young harp seals fed on herring required 6%–8% of body weight per day, and Bonner (1982) quotes Geraci (1975) as stating that adult harp seals consumed 4%–7% a day. Spalding (1964) quotes Scheffer (1958) as giving the daily food intake of northern fur seals and Steller sea lions as 7% and 2% respectively. Ronald et al. (1984) quote ICES (1981) as giving the food requirements of grey seals as 3%–5% of body weight per day. California sea lions at the London Zoo consume some 5%–10% of body weight per day, but these include rapidly growing young animals (Gulland, 1986).

These results indicate that most seals in captivity can remain healthy and active on a diet of about 4%–6% of body weight a day. The data are not suitable for attempting to examine the relation between the rate of feeding and the size of the seal. It is less clear whether the seals in these experiments were maintaining normal growth or the amount of activity required of a seal in the wild. Bigg (1985) reported that female northern fur seals kept in tanks and swimming actively consumed about 6% of body weight per day. He stated that fur seals kept in tanks large enough to allow them to swim actively appear to maintain about the same level of activity as they would under natural conditions. In contrast to the above, Nightingale (pers. comm. to Bonner, 1982) found that northern fur seals kept in large tanks required 26%–27% of body weight a day to maintain normal body growth. The discrepancy with the results of other observers seems remarkable, but no evidence is available as to whether these animals appeared overfed.

Energy Requirements

Study of the energy requirements of seals as a means of estimating their food requirements is complex, but has two major potential advantages. In the first place, it should lead to a better understanding of the processes involved, and of any fundamental errors which may arise in approaching the problem. Secondly, because of the general nature of the processes, it may be possible to make use of data which have been obtained from study of other mammals. Its major disadvantage is that such studies generally require long-term and continuing detailed observations of the food consumption, excretion, activity and so on of seals kept under carefully controlled conditions.

Lavigne et al. (1982, 1985) have reviewed the work which has been done on the energy requirements of seals and the relation to the food consumed. The available data indicate that about 67%–75% of the energy in the food consumed by a seal is available to support basal metabolism, activities, growth and reproduction. The remainder is lost in faeces, urine and other waste products, and in waste heat. The data suggest that the energy required by resting seals for their basal metabolism does not depart greatly from a formula applied to mammals in general by Kleiber (1975). This is:

$$M = K\,W^{0.76}$$

where, if M is basal metabolism in kilocalories/day, and W is the weight of the seal in kilograms, then K, a species-specific growth constant, equals 70. Lockyer (1985a) used a similar equation with the same multiplier and an exponent of 0.7325 for grey seals. This relation means that the amount of food required increases more slowly than the weight of the seal; for instance, if the weight is doubled, the food requirement increases 1.69 times, and if the weight is quadrupled (e.g., from 50 kg to 200 kg) the food requirement increases 2.87 times.

The problem in applying this relationship to seals in natural populations is that animals in the wild require energy for purposes additional to basal metabolism; these purposes include: swimming (for feeding and migration), growth, reproduction (Anderson and Fedak, 1985; Fedak and Anderson, 1982), and temperature regulation. Thus if Kleiber's relation is used to estimate the energy requirements of wild seals, K must be given a value substantially higher than 70.

Lavigne et al. (1985) examined the results of laboratory experiments measuring the energy requirements of seals which were not under the restricted conditions leading to $K = 70$. They found that many of these obser-

vations fitted to curves for $K = 140$. Most of the animals observed were active, but were neither growing nor reproductively active.

Innes et al. (1985) reviewed a large amount of data on the energy and biomass requirements of seals and other marine and terrestrial mammals. They concluded that "rates of food consumption by marine and terrestrial mammals do not differ significantly when comparisons are made under appropriate standardized conditions." They also found that estimates of the daily energy requirements of many animals, including seals, fell "within the expected range of 1.5 to 3.0 times the basal metabolic rate predicted for mammals by Kleiber's equation": that is, $K = 105\text{–}210$. Lockyer (1985a, 1985b) reviewed the available data on the energy requirements of harp and grey seals (kcal/day) when provision is made for activity and reproduction. Her results may be summarized as follows:

	Grey Seal	Harp Seal
Breeding bull	19,000	11,000
Breeding cow	14,000	10,000
Pup	5,500	4,000
Mature male	12,376	
Mature female	9,464	

Lavigne et al. (1982) used the population model of Benjaminsen and Lett (1976) to calculate the average individual energy intake (without allowing for growth or reproduction) of the northwest Atlantic harp seal herd. They obtained a value of 6,050 kcal/seal/day.

Fedak and Hiby (1984) calculated the energy requirements of the U.K. grey seal herd, taking account of activity, growth and reproduction, and obtained an average figure of 5,860 kcal/seal/day. These workers used a linear function relating energy requirement per kilogram of body weight with age, rather than a Kleiber-type relationship.

These estimates of daily energy requirement and the approximate body weights of the animals have been used to calculate the corresponding values of K given in Table 24.7, together with observations by Lavigne et al. on basic metabolic rates. The table also includes the value of K used by Antonelis and Perez (1984) for female northern fur seals (converted from a value of M measured in megajoules in the original).

These values of K cover a wide range (105–375, excluding that for basal metabolism only). The differences arise not only from possible biases in some estimation techniques, but also from differences in the species, age, growth rate and reproductive condition of the animals examined. It seems likely that a representative value of K to be applied to calculations for a seal population as a whole would be in the range of 200–300.

Some researchers have also addressed the question of whether the energy requirement of a single population could change in a density-dependent manner, through such factors as effects on growth rate and age at maturity. There does not appear to be agreement at present as to whether such changes would occur, or in which direction they would operate (Brodie and Påsche, 1982; Winters, 1975). However, any effects of this kind are negligible in relation to the uncertainties still existing in the estimates of total population energy requirements.

Conversion of Energy to Food Requirements

Calculating the approximate amount of food consumed from estimates of energy requirements requires information on the energy content of the prey. Data on energy values have been tabulated by Lavigne et al. (1982, Table 3), McConnell et al. (1984, Table 6.3), and Perez and Bigg (1985, Table 3). The values in kcal/g wet weight of flesh range from 2.0 to 2.2 for oily fishes like herring, to about 0.8 to 1.0 for fish like cod; both shrimp and squid have values of about 1.2–1.3. Many fish, however, have substantial seasonal fluctuations in energy value as they go through their annual cycles. Among other factors which affect the amount of energy obtained by the seal from prey are the amount of inedible material (high in shrimps, for example) and the size of prey (seals may swallow small fish whole, but discard heads and other parts of large fish).

Assuming the weight of the seal, the energy content of the prey, and the value of K in the Kleiber equation, it is possible to calculate daily food consumption as a percentage of seal body weight. A range of results is shown in Table 24.8. The percentages, particularly for $K = 200$ and 300, are quite consistent with estimates based on direct observation.

Lockyer (1985a) reviewed direct data and energy considerations to conclude that the daily food requirement of grey seals is probably 5%–6% of body weight, but emphasized that the energy content of the food affects this value.

Table 24.7
Available Estimates of the Value of the Constant *K* in the Kleiber Equation

Species	Category	Approx. Mean Weight (kg)	Daily Energy Consumption (kcal)	*K*	Source
Harp	Population model	80	6,050	216	Lavigne et al. (1982)
Harp	Breeding bull	135	11,000	264	Lockyer (1985b)
Harp	Breeding cow	120	10,000	263	Lockyer (1985b)
Harp	Pup	35	4,000	268	Lockyer (1985b)
Grey	Population	135	5,860	141	Fedak and Hiby (1984)
Grey	Breeding bull	212	19,000	324	Lockyer (1985b)
Grey	Breeding cow	147	14,000	315	Lockyer (1985b)
Grey	Pup	50	5,500	281	Lockyer (1985b)
Grey	Mature bull	212	12,376	211	Lockyer (1985b)
Grey	Mature cow	147	9,464	213	Lockyer (1985b)
Northern fur	Mature females	35	–	375	Antonelis and Perez (1984)
General seals	Basal metabolism	–	–	70	Lavigne et al. (1982)
	Active in captivity	–	–	140	Lavigne et al. (1985)
General mammals	Daily energy requirement	–	–	105–210	Innes et al. (1985)

Table 24.8
Calculated Daily Food Consumption as Percentage of Body Weight[a]

Weight (kg)	Energy Conversion Factor (kcal/g)	*K* in Kleiber Equation		
		100	200	300
100	0.8	3.9	7.9	11.9
	1.4	2.3	4.5	6.8
	2.0	1.6	3.2	4.7
200	0.8	3.3	6.6	9.9
	1.4	1.9	3.8	5.7
	2.0	1.3	2.7	4.0
300	0.8	3.0	6.0	9.0
	1.4	1.7	3.4	5.1
	2.0	1.2	2.4	3.6

a. Calculated for a range of body weights, prey energy contents, and values of *K* in the Kleiber equation.

Following these results the daily rates of consumption used in estimating the total food consumption of seal populations will be 6% of body weight for the smaller seals such as harbour seals and female and juvenile northern fur seals, and (scaled down roughly in inverse proportion to the 0.25 power) 5% and 4% for the larger species. For the relatively small northern fur seals which visit Canadian waters the figure of 6% may be disproportionaly low, but since, as will become apparent, no significant impact is involved, 6% will be used for all the smaller seals.

In calculating estimates of the total food consumption of seal populations, the main uncertainties lie in the size of the seal populations, the energy requirements of individual seals and the energy content of prey species. Each of these estimates is subject to error, but the extent of this error is not known, and it is impossible to give precise confidence limits. If we assume,

as a rough generalization, that the confidence limits for each of these three factors are likely to be about ± 25% of the true value, and that the errors are independent, then a simple model would calculate the confidence limits for the estimates of total food consumption as:

$$3 \times 0.25^2 \times 100 = \pm 43\%.$$

Considering the uncertainties in the confidence limits of the individual factors, combined confidence limits of ± 40% seem appropriate.

How Much of the Commercially Important Species Do Seals Eat?

Total Food Consumption by Species

The first stage in calculating the annual amount of each prey species consumed by each species of seal is to estimate the total food consumption of that seal population as the product of the number of animals in the population and the average food consumption per seal. These calculations, for the species of seals which are of significance in this Report, are set out in Table 24.9. Ideally, such calculations should be done with structural population models, taking into account the effect of such factors as growth and reproduction on each age group. The Commissioners do not believe, however, that sufficient information is available even for such relatively well-studied species as the harp seal and northern fur seal for this to be done effectively. To attempt to do so might only give a spurious appearance of accuracy to the results.

There is evidence for harp (Sergeant, 1973), grey (Parrish, 1979; Ling, 1969) and harbour (Venables and Venables, 1955) seals that the animals may fast for periods of several weeks during the moulting and whelping seasons. During these times energy is still being consumed, at least for basal metabolism, and the animals lose condition. Subsequently, however, an additional food intake is required to restore their reserves. No allowance is therefore made for these fasting periods in the calculations in Table 24.9.

Table 24.9
Estimated Total Annual Food Consumption of Canadian Seal Herds

Species	Present Population[a] (1000s)	Mean Wt. (kg)	Daily Consumption (%)	Total Food Consumption (1000 tonnes)
Harp	2,000	80	6	3,500
Hooded	300	350	4	1,5000
Harbour:				
East coast	13	60	6	17
West coast	45–60	55	6	54–72
Grey	70	190	5	240
Northern fur:	870	M 180	5	1,800
Total Pribilof herd		F 35	6	
Off B.C. coast	20–30 (5 months)	26	6	4.7–7.1
Steller sea lion	4.8–6.6	M 350	4	19–26
		F 150	5	
California sea lion Off B.C. coast	4.5 (5 months)	180	5	6

a. From Chapter 21 and 22.

The values used in Table 24.9 for the population size and mean weight of the northern fur seal require special mention. They make allowance for the fact that only part of the population spends only part of the year off the B.C. coast and thus has an impact on Canadian fish stocks. The adult males remain throughout the year in northern waters, but the younger animals (one to four years) and the females of all ages undertake extensive southward migrations, mostly within 130 kilometres of land (United States, 1985). It is during these migrations that they enter Canadian waters. The

younger animals appear in Hecate Strait and other inshore waters about January and remain there until about the end of May. The main herd of the older females remains farther offshore, and the animals migrate farther along the U.S. coast, many as far as California. In April the main herd is off British Columbia on its northward journey and the young animals move out of the inshore waters to join it. By June only a few late migrants are left (Spalding, 1964). Antonelis and Perez (1984) give the results of a number of counts of northern fur seals off the coasts of Washington, Oregon and California. For Washington, the state nearest to British Columbia, the average count for the months January to May, when fur seals were abundant, was 68,000 animals. Bigg (1985) believes that the number on the B.C. coast is perhaps about 20,000–30,000 animals, and this figure has been used in Table 24.9. The mean weight is the weighted mean of the values given by Antonelis and Perez (1984) for the months January to May off the Washington coast.

On the Atlantic coast, it is important when assessing the impact of consumption by seals on the fishery, to examine the local distribution of the seals and of the fishing activities. For this purpose the northwest Atlantic–Davis Strait area adjacent to the Canadian coast has been divided into six areas (Figure 24.1) based on the North Atlantic Fisheries Organization (NAFO) subdivisions.

In Table 24.10 the total food consumption by each species of seal, as given in Table 24.9, has been subdivided between these areas, on the basis of what is known of the distribution and migration of each species.

For the distribution of harp seal food consumption among these areas, the Royal Commission is indebted to Dr. W.D. Bowen. Using the following assumptions:

- there is a lactation period of 12 days during which mothers fast;
- mothers represent 25% of the adult population;
- all animals aged one year and older fast for 14 days during the annual moult;
- age groups one to five years (juveniles) comprise 55% of population;
- harp seals spend equal amounts of time north and south of the 2H–2J NAFO line;

Figure 24.1
Areas Used in Discussion of Fish Consumption by Seals

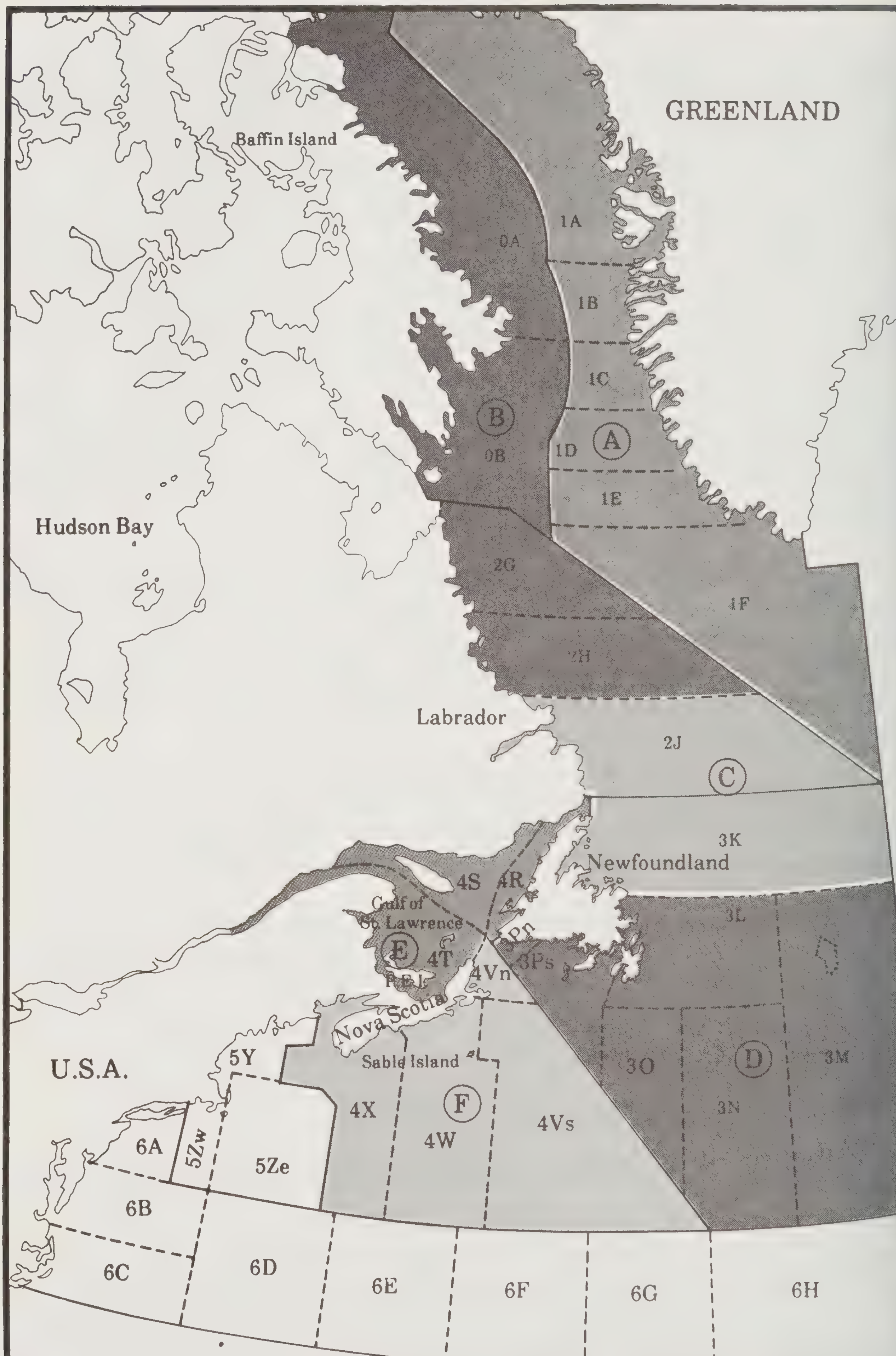


Table 24.10
Estimated Total Food Consumption by Species in the Principal Atlantic Fishing Area

Areas		NAFO Subdivisions	Seal Consumption (1000 t)				
			Harp	Hooded	Grey	Harbour	Total
A:	W Greenland	1 A – F	1,200	500	–	–	1,700
B:	N Canada	0,2 G – H	1,000	500	–	–	1,500
C:	S Labrador/ NE Nfld.	2 J, 3 K	800	500	–	–	1,300
D:	SE Nfld.	3 L – P	250	–	24	2	276
E:	Gulf	4 R – T	250	–	130	8	388
F:	Scotian Shelf	4 V – X	–	–	86	7	93
Total			3,500	1,500	240	17	5,257

- about 75% of juveniles and 25% of adults summer off west Greenland;
- about 20% of juveniles remain off west Greenland in winter (see Larsen, 1985);
- one-third of adult males and females feed in the Gulf of St. Lawrence, as well as 20% of the juveniles which migrate south;
- the remainder feed at the Front;
- all animals migrate along the Labrador coast (2GH) before crossing Davis Strait or Hudson Strait and return along the Labrador coast in the fall;
- food requirements are independent of body size (not a very good assumption); and
- the caloric value of food is the same in all areas.

Bowen (1986) calculated the approximate percentage distribution of harp seals in each area to be:

Area	%
A	34.0
B	29.0
C	22.5
D	7.5
E	7.0
F	0.0

These figures are consistent with the estimate of Northridge (1986) that 62% of the food of harp seals is taken in the summer, when they are predominantly in Areas A and B, and 38% in winter when they mainly occupy Areas C to F. The distribution within the latter areas is also similar to that shown on the map published by Northridge (1986).

The allocation of hooded seals among areas is based, in the absence of better information, on the assumption that their feeding activities are equally distributed among the three northern areas, which are the only ones in which they occur in significant numbers.

For grey and harbour seals the allocations have been based on available information about the distribution of the species, taking into account the relative extent of the coastal seas within each of the southern areas. The small northern populations of harbour seals, and of grey seals in summer, have been ignored.

Table 24.11 compares the estimated total seal consumption in each of these areas with recent total and Canadian commercial catches. It is apparent that, although both harp and hooded seals feed heavily in Areas A and B, the Canadian catches in them are extremely small. Unless there is a very substantial increase in Canadian fishing effort in these areas, it does not seem likely that any change in the seal populations would have any significant effect on those Canadian catches. In Areas C to F, on the other hand, there are major Canadian fisheries, and the significance of any impact requires further examination.

Table 24.11
Comparison of Total Seal Consumption with Total and Canadian Commercial Catches

Area	Total Seal Consumption (1000 t)	Commercial Catch (1000 t)		Percentage Composition of Catch				
		Total	Canadian	Cod	Haddock	Redfish	Herring	Prawn
A	1,700	117	–	45	–	–	–	31
B	1,500	19	5	–	–	–	–	42
C	1,300	369	320	46	–	–	–	–
D	276	189	96	49	–	27	–	–
E	388	294	285	45	–	–	12	–
F	94	457	290	25	11	–	25	–
Total	5,258	1,445	996					

Note: Catches for 1981 are from NAFO (1983).

Breakdown of Food Consumed by Species

It is clear that the data available on the composition of the food of seals are not sufficient to make possible precise estimates of the amounts of individual fish species consumed. All that can generally be done is to identify groups of prey species which play a similar role in the diet of seals, as well as in relation to the commercial fisheries, and to make educated guesses at the possible range of the proportion each group makes up in the seals' food. In the following sections, these educated guesses are combined with the estimates of total food consumption to develop possible figures for the amount of each of the principal prey groups consumed. These results will later be compared with sizes of the catches and what is known of the stock sizes of the various prey species.

In a thorough analysis of the impact of seals on commercial fisheries and especially on individual fishermen or groups of fishermen, it would be important to distinguish between different stocks of the same species of fish. The extreme example is salmon, where each river or stream may have its independent spawning stock, and a seal colony located at the mouth of a salmon river might have a serious impact on the fisheries in that river, even though their consumption of salmon, as a proportion of all salmon caught along the whole coast, might be small.

Stocks of marine fish are less distinct and less finely divided, but may still be differently affected by seal predation. The east coast herring are a case in point. The total consumption of herring by harp seals is small, compared with the total herring biomass, but the 4T stock in the Gulf of St. Lawrence may possibly suffer quite intense predation in the spring, and the impact on this stock may be significant.

In practice, the data on seal feeding are seldom, if ever, good enough to attempt a detailed stock-by-stock analysis, and they will have to be examined here in terms of the fish species as a whole. However, the possible differences among stocks should be borne in mind, especially when considering the possible impact on particular groups of local fishermen.

Harp Seal

It has been generally accepted that capelin form a major component of the food of harp seals (Beddington and Williams, 1979b), and the data reviewed earlier, although very sparse, do not contradict this. Sergeant (1973) used an estimate of 25% capelin in the food of harp seals as a basis for discussion, and this still seems to be a reasonable figure for the winter food in Areas C to F in the 1970s. The data, limited though they are, do show that harp seals not infrequently eat capelin, but they eat other food as well, so that possible limits to the range might be taken as 10%–40%. On this basis, using 1.3×10^6 t as the estimate of current harp seal consumption in Areas C to F (Table 24.10), we obtain 325,000 t as a central figure and about 130,000 t –520,000 t as the likely range if capelin had continued to be as abundant as they were in the 1970s. Since that time there have been major changes, as discussed later, in the abundance of capelin in the northwest Atlantic; at one time, indeed, capelin were only about one-quarter as abundant as in 1970. A conservative estimated range of 30,000 t–130,000 t might be more appropriate to present conditions.

There is no good evidence concerning the proportion of capelin in the food of harp seals during the summer in Areas A and B, but it could well be higher than in winter. However, since these stocks are fished very lightly, if at all, by Canadian fishermen, the impact of seals on their catches in these areas will be ignored.

The year-class strength of capelin of the Labrador–Newfoundland stock (Area C), on which harp seals feed in the winter, can vary from year to year by as much as a factor of 8, and this has been shown to be largely the result of environmental factors (wind and temperature) (Leggett et al.,

1984). The opportunistic feeding behaviour of seals probably implies that, as a result, there will be substantial variations in the quantities of capelin consumed by harp seals, and that other foods will make up much of the difference. The same effect will apply to other capelin stocks, as well as to herring and shrimp.

Unlike capelin, herring overlap with harp seals in their distribution to only a limited extent (Northridge, 1986); the main coincidence is in the southern Gulf of St. Lawrence (NAFO Area 4T) in the spring. Sergeant (1973) brought together what was known of the movements of the two species to obtain an estimate of the amount of herring consumed by harp seals in this area about 1970, obtaining a figure of 21,500 t. This was calculated on the basis that the seals in this area were feeding exclusively on herring for a period of 60 days, and that during this period the proportion of seals actively feeding increased, although the number present gradually diminished. A mean feeding rate of 5 kg per day was used. If the *per capita* consumption has not changed, the estimate of current total consumption would have to be scaled up, to allow for an increase in the seal population from 1.3 to 2 million; this would give an estimate of current consumption of 33,000 t.

The Gulf herring stocks are now less abundant then they were in the 1970s. Ahrens and Nielsen (1984) have shown that between 1970 and 1985, the Area 4T herring stock declined to about one-fifth of its initial value. Thus it is likely that current consumption by seals has also dropped. Northridge (1986) ran a simulation of the 4T stock of herring, using the mean logarithm of recruitment over the period 1971–1973 as an index of stock size. Using a fairly extreme assumption, that seals accounted for three-quarters of the natural mortality (assumed $M = 0.2$), he obtained an estimate of total consumption by seals of 7,000 t. If the assumption about the size and population dynamics of the herring stock are correct, this implies that herring constituted a much smaller proportion, perhaps one-third as much, of the diet of harp seals as was assumed by Sergeant. At the present time, with the herring stock substantially reduced and the seal population increased, the proportion of herring in the seals' diet must have been further reduced, and the extrapolation to 33,000 t cannot be sustained. Since the abundance of herring has been reduced to about one-fifth, and seals are generally regarded as opportunistic feeders, it may be more realistic to regard the present consumption of herring in the Gulf as about one-fifth of that estimated by Northridge for the 1970s, or in the range of 1000 t–3,000 t. This estimate may be conservative, however, since it does not allow for the increase in the seal population in the interval.

Some additional consumption of herring takes place outside this period and outside this area, but the data do not enable any estimate to be made of these amounts. There may also be substantial differences from year to year in spring consumption of herring in the Gulf, since both species involved may vary in their local abundance in response to environmental conditions.

The situation relating to shrimp is even less clear. Decapods (unspecified) or *Pandalus* spp. are not infrequently recorded in stomachs (Table 24.1), from which it seems possible that this group of animals could make up 5%–15% of the winter consumption, or 70,000–210,000 t. It is not known how much of this is *P. borealis* or other commercial species. Northridge (1986) suggested that the total biomass of *P. borealis* in Canadian waters might amount to about 100,000 t. The possibility therefore exists that the consumption of shrimp by harp seals represents a high proportion of the stock, but the data are not good enough to confirm or reject this possibility.

Harp seals occasionally eat various species of demersal fish. In a later section, it is estimated that these species may possibly constitute about 7%–12% of their diet, but the data are scanty, and the confidence limits for these estimates are, therefore, very wide. These seals may also eat some pelagic species other than capelin and herring but only a single specimen of one such species (barracudina) is recorded in Table 24.1.

If, however, as suggested above, the amounts of herring and capelin eaten by harp seals have declined substantially since the mid-1970s as a result of the decrease in the stocks, harp seals, which have increased in numbers during the interval, must have increased their consumption of other prey species, although there are no data as to which species these may be.

Harbour Seal

Boulva and McLaren (1979) state that in eastern Canada the most frequently occurring food items found in the stomach of harbour seals were herring (24%) and flounder (14%). Fisher and Mackenzie (1955) found that herring made up 37% by volume of the stomach contents they examined, and flounders and other flatfish made up 18%. If these frequencies of occurrence actually represented proportions in the food, and the samples were representative of the total seal population, these figures would correspond to a consumption of about 4,000 t–6,300 t of herring, and 2,400 t–3,000 t of flounder.

Northridge (1986) compares the estimated consumption of herring by harbour seals in Area 4WX (mainly south of Nova Scotia) with the yield of the fishery. Taking the number of harbour seals in the area as 5,900 in 1973 (Boulva and McLaren, 1979), and applying the mean weight and rate of consumption used in Table 24.9, the total consumption becomes 7,800 t. (Northridge, using slightly different parameters, obtains 10,000 t.) It is estimated elsewhere (Chapter 21) that the Atlantic coast harbour seal population in 1985 was not far from the 1973 level. If this applies to the population in Area 4WX, and on the assumption that the diet includes 25%–37% herring, then the range of the estimate of herring consumption is about 2,000 t–2,900 t.

The data in Table 24.3 also suggest that about 30% of the food of harbour seals on the Atlantic coast consists of commercially important demersal fish such as flatfish, gadids and redfish. No data have been found for the east coast suggesting that harbour seals take salmon in the estuaries as they are returning from the sea to spawn.

On the west coast of Canada, however, the situation seems to be rather different, and harbour seals appear to feed extensively on salmon in the narrow waters of the B.C. coast and up the river estuaries. Stewart (1983), for instance, records aerial surveys as showing 1,330 harbour seals in the "Fraser River area". In Table 24.9 the total amount of food consumed in a year by west coast harbour seals is estimated at about 60,000 t. As noted in a previous section, the proportions of salmon and herring in the stomachs examined were 23% and 11%, and these would correspond to a consumption of 14,000 t and 6,600 t respectively. It is likely that these figures overestimate the amount of salmon consumed and underestimate the amount of herring. Stewart (1983) examined the combined biomass of six species of salmonids entering the Fraser River, and his figures show that almost 97% of the total biomass enters in the five months of June to October. Since the great bulk of the samples reported on by Spalding (1964) were taken in these months, it is likely that a better estimate of the proportion of salmon in the total harbour seal diet is five-twelfths of 23%, or 9.5%; this proportion corresponds to an estimated consumption of about 6,000 t of salmon.

The most uncertain figure in these calculations is, of course, the 23% salmon in the food consumed during the months when salmon are available to the harbour seal. It is not possible to attach statistical confidence limits to this figure, but a factor of 2 in either direction might be not unreasonable.

Grey Seal

Table 24.9 estimates the food consumption of grey seals on the Atlantic coast as about 240,000 t. Grey seals feed on a wide variety of fish species, but the data in Table 24.5 show consistently for Canada, Iceland and the British Isles that there is a high proportion of commercially important species in their diet. These consist of both demersal and pelagic species, but in Europe the demersal forms predominate strongly; in Canada the data include 50% demersal, 37% pelagic, 1% sand lance and 13% other non-commercial species. There will certainly be a great deal of variation in the detailed specific composition by both time and place, and it is not possible to make useful estimates of the amounts of any particular species that are consumed. Nevertheless, it seems clear that a very large proportion of the food of grey seals consists of commercially important species, probably within the limits of 60%–90%. Comparison of the results in Table 24.5 also indicates great variation in the relative amounts of demersal and pelagic species. While these comparisons are between major geographical areas, it seems likely that there will be similar variability on a smaller time-space scale within Canada.

Mansfield and Beck (1977) calculated separately the amounts of each of the principal prey species consumed in each of three areas – Gulf of St. Lawrence, Sable Island and eastern Nova Scotia – on the basis of their estimates of the numbers of grey seals in each area and the corresponding stomach-content data. It is not possible to determine the total amount of commercially important species in these weighted estimates but, re-combining the three areas, the proportions of the most important species are:

herring	23%	cod	14%
skate	19%	squid	6%
flounder	16%	mackerel	5%

For the purpose of future calculations, it will be assumed that 70% of the total commercial fish in the diet of grey seals (60%–90%) consists of demersal species, and the rest of pelagic fish in the form of herring. The effect of the variability in the proportion of total commercial species that are pelagic species, which is not being taken into account in this calculation, would be quite small compared to the variability of total commercial species within total consumption, which is being included in the calculations. The Gulf herring stocks have, however, declined substantially below their level at the time when most of the seals reported by Mansfield and Beck (1977)

were collected, and it is possible, therefore, that the proportion of herring in the grey seal diet is now lower than their data indicate.

While concern is often expressed about the consumption of salmon by grey seals, the amount is also very difficult to assess. This is because of the very localized effects of any predation which may occur when salmon are running along the coasts and into river mouths. Northridge (1986) cites evidence from the United Kingdom and the Baltic which suggests that "seal predation on salmon may have little to do with absolute seal numbers, with just a few seals accounting for most of the predation." If this is so, it is clearly impracticable to try to estimate the amount of salmon consumed using the methods employed here.

Northern Fur Seal

The amount of food consumed by fur seals on their winter and spring migration off the B.C. coast is estimated at about 5,000 t–7,000 t. Of this amount, the major components are herring, salmon and squid. The last includes a number of species, not all of which are of any commercial significance. Applying the percentages given earlier (from Perez and Bigg, 1985) provides estimates of the amounts consumed as: herring 2,100 t–3,000 t; salmon 1,000 t–1,400 t; and squid 1,000 t–1,400 t.

Spalding (1964) states "the northward migration of fur seals off the west coast of Vancouver Island coincides with the offshore movement of herring out of Barkley and Clayoquot Sounds after spawning which reaches a peak in mid-March." He shows an apparent relation over years between frequency of herring in the fur seals' stomachs and the size of the adult herring population as measured by "miles of spawn" deposited. It is very doubtful, however, if this relation, based on a total of 139 stomachs over four years, has any statistical validity.

Steller Sea Lion

The estimated total food consumption of this species, shown in Table 24.9, is 19,000 t–26,000 t. Application of the figures for food composition supplied by Bigg (1985) leads to the following estimates of the amounts of the major prey species consumed: herring, 5,500 t–8,000 t; and dogfish, hake, salmon, eulachon, and squid each about 2,700 t–3,600 t. As noted earlier, there are major variations from time to time and place to place, particularly as regards salmon and herring. The relative availability suggests, how-

ever, that herring would be more important in the winter and early spring, and salmon in the summer months. These calculations are based on the number of Steller sea lions breeding on the B.C. coast rookeries. If, as seems not impossible, the number of sea lions breeding on the large Forrester Island rookery in Alaska and feeding in Canadian waters exceeds the number of Canadian-bred sea lions feeding in U.S. waters, the above figures will tend to be an underestimate of the total food consumption by Steller sea lions in Canadian waters.

California Sea Lion

The total food consumption of California sea lions off the B.C. coast is estimated at about 6,000 t. Since this sea lion is present on the B.C. coast only in the winter, when the adult herring are making their mass migration (Hourston and Haegele, 1980), it is appropriate, as discussed in the previous section, to apply the factor of 50% to calculate the amount of herring consumed by this species; this calculation produces a figure of about 3,000 t. The other 3,000 t will presumably be made up of a variety of species, including those listed for Steller sea lions. Since, however, the time of the California sea lions' presence does not overlap with the major salmon runs, the amount of salmon consumed may be relatively small.

Summary

The foregoing sections suggest that the principal commercial fish stocks which may be subject to significant predation by each species of seal are:

On the east coast:

harp seal:
- capelin, throughout the range;
- herring, in the Gulf of St. Lawrence in the spring;
- shrimp, in the Gulf, off west Greenland, and on the northeast Newfoundland Shelf;

harbour seal:
- herring, flounder and other commercial demersal fish;

grey seal:
- commercial fish generally, possibly Atlantic salmon;

hooded seal:
: deep water demersal species, e.g., redfish, but no adequate data.

On the west coast:

northern fur seal:
: herring, squid, possibly salmon;

harbour seal:
: salmon, herring, possibly other commercial species;

Steller sea lion:
: salmon, herring, commercial fish generally;

California sea lion:
: herring.

Comparison of Predation with Stocks and Catches

In this section the information available on the amounts of fish consumed by seals is compared with estimates of biomass and commercial catch for the fish species most likely to be affected by seal predation.

Capelin

Capelin consist of a number of more or less distinct stocks. The Greenland stock (Areas A and B) supports a large part of the harp seal population during the summer feeding season, but this stock is not fished by Canada. The largest of the stocks that are fished by Canada is that in the southern Labrador–northeast Newfoundland area (Area C).

Bowen (1985) and Northridge (1986) have reviewed recent data on the size of this stock. It has been subject to a significant fishery since about 1971; catches rose rapidly to a peak of about 300,000 t in 1973–1976 and fell again, in 1979, to less than 35,000 t. The average catch over 1972–1978 was about 230,000 t. The estimated biomass of capelin in the NAFO Divisions 2J and 3K, which correspond with the distribution of this stock, has fluctuated

widely, apparently largely because of environmental effects (Leggett et al., 1984). It rose to a peak of about 4 million t in 1975, then declined to about 0.5 million t in 1978; it amounted to 223,000 t in 1983, and to about 860,000 t in 1984.

For statistical Area 3LNO, which forms part of our Area D, Beddington and Williams (1979a) quote Carscadden and Miller (1979) for estimates of biomass southeast of Newfoundland as ranging between 3.7 million t in 1973 and 0.6 million t in 1978. That biomass subsequently fell to 280,000 t in 1984 (Northridge, 1986). The stocks in the Gulf of St. Lawrence (Area E) and Division 3Ps (part of Area D) are much smaller, about 4,000 t (Northridge, 1986).

Northridge (1986) estimates the current total biomass, excluding Greenland stocks, at about 1.2 million t. Using a natural mortality rate of 1.2, he calculates natural deaths as about 840,000 t annually. A substantial, but unknown, part of this mortality would be attributable to predators.

The available estimates of capelin biomass, fisheries catch and consumption by harp seals in the areas (other than A and B) used in Figure 24.1 and Table 24.10 can be summarized as follows (quantities in thousands of tonnes):

Area	Capelin Biomass	Fisheries Catch	Harp Seal Consumption	Consumption by Other Predators
C	223 – 4000 (1200)	35 – 300	20 – 80	1700 – 3800
D	(250?)	5 – 200	6 – 25	
E	2	0.4	?	
F	0	0	0	

Note: Figures in parentheses are estimates of current biomass.

The estimated consumption of capelin in Areas C and D is calculated by distributing the estimated total of 30,000 t–130,000 t in proportion to the consumption for those areas given in Table 24.10. A similar calculation for Area E (Gulf of St. Lawrence) would give a figure equal to that for Area D, which is about an order of magnitude greater than the estimated biomass.

This suggests that either food consumption in the Gulf is greatly overestimated, or that capelin form only a small proportion of the food of harp seals in this area. In these circumstances it does not seem possible to make any useful estimate of the amount of capelin eaten by harp seals in the Gulf. This observation must also add to the uncertainties about the estimates for the other areas, particularly since most of the data about the occurrence of capelin in harp seal stomachs are derived from seals taken in the Gulf.

For both biomass and catch, the ranges of values given for Areas C and D cover the variations in the estimated and reported values respectively, which have resulted from changes in abundance and fishing intensity since the early 1970s (figures in brackets are estimated current biomass). For consumption, on the other hand, the ranges given derive from the uncertainties in the proportion of the food consisting of capelin, on the assumption that the total food consumption is that estimated for the present seal population; a further ± 40% should be imposed to allow for uncertainties in total food consumption, as discussed earlier. These results suggest, very broadly, that the amount of capelin eaten by harp seals in these areas is of the same order as the catch in the commercial fishery. However, the very wide variations from year to year in the abundance of capelin and in the intensity of the fishery must complicate the relationship between catch and consumption. While the total food consumption of harp seals is likely to have changed in fairly close proportion to their abundance, their opportunistic feeding behaviour makes it probable that they have made large changes in the composition of their food in response to the fluctuations in capelin abundance, and that they have eaten correspondingly fewer capelin when the stock has been small.

The total food consumption of the hooded seal is about half that of the harp seal. It is not possible to estimate how much of the food of hooded seals consists of capelin taken from stocks of concern to the Canadian fishery, but this amount is likely to be less than that taken by harp seals. There are several reasons for this. The more northerly distribution of the hooded seal herd means that more of these seals spend a greater proportion of their time in Areas A and B; part of the population breeds on the ice in Davis Strait, well north of the harp seals at the Front; only very small numbers of hooded seals go as far south as Areas D and E. Secondly, the hooded seals at the Front breed seaward of the harp seals and may be outside the areas where capelin are abundant. Finally, the hooded seal feeds at a greater depth and commonly takes larger fish than the harp seal, whereas the capelin is small and frequents the upper layers of the water. The observations from Greenland in Table 24.2 suggest strongly that capelin is a comparatively minor food of hooded seals.

No other species of seal seems to be of any significance as a predator on capelin.

Capelin are also subject to predation by a number of species in addition to seals. Major predators which have been identified are Atlantic cod, seabirds, Atlantic salmon and whales. Lilly et al. (1981) estimate annual consumption by Atlantic cod in Divisions 2J, 3KL and 3NO as 1.2 million t –3.3 million t. Carscadden (1983) estimates that seabirds consume 0.25 million t of capelin annually. Beddington and Williams (1979a) show estimates of the combined consumption by minke and fin whales of 0.28 million t. All these amounts must presumably be subject to large variations from year to year in response to the changes in the abundance of capelin.

All figures for consumption by other predators have been derived by the same kind of techniques as have been used to obtain estimates of consumption by harp seals. It seems that the seals are only one of a number of major predators on capelin, and that Atlantic cod are the most important. The figures given above would appear to suggest that seals may account for about 1%–5% of the total predation. However, since the estimates of amounts of capelin consumed by other predators apply to a time when capelin were more abundant than in recent years, the above comparison with current consumption by seals has probably produced an underestimation of the percentage of total predation which is due to seals.

As Northridge (1986) points out, these figures lead to an estimate of total predation which is substantially greater than the estimate of total natural deaths obtained by multiplying current stock size by natural mortality rate (M). This discrepancy may be explained, at least in part, by the substantial variation in capelin abundance, and the fact that the estimates of biomass exclude the young, pre-recruit fish. It also illustrates, however, the general level of uncertainty in attempts to quantify the relationship between fish stocks and their predators, even in such relatively well-studied cases as harp seals and capelin.

The capelin eaten have, apparently, not been measured or aged. It is possible, however, that the capelin eaten by the seals in January–June are in the main the larger capelin which would have spawned in June–July, about one to five months later than when they were taken by the seals. Whales are present, feeding on capelin, in and after May–June. The Newfoundland fishermen and the nesting seabirds on the coast typically take their capelin when they approach the coast for spawning in June–July–August. The northern cod over the NAFO Division 2J–3K area are moving to deep and moderately warm water in January–February and spawning there mainly

in March–April, though some spawning occurs in May; they are not eating much over a good deal of this period. In any case, the northern cod spawning grounds are in temperatures somewhat seaward of the capelin, which at this time occupy more coastal, colder waters and are not being preyed on significantly by these spawning northern cod.

The Newfoundland fishermen concentrate, as far as possible, on the larger female capelin which would spawn earliest and on the beaches, but they try to take them for their roe and therefore before spawning. On the east coast of Newfoundland, the capelin which have escaped the human, mammal, fish and bird predators begin spawning at or near the beaches. The larger capelin begin to spawn in the latter part of June, and the younger and smaller fish continue spawning throughout July and to some extent in August, in gradually deeper water close to shore as the season advances. Inevitably, if there is considerable selection for the larger fish, most of the capelin spawning will be the smaller young fish, which are commercially less desirable.

The seals, therefore, are the first in line to prey on the ripening capelin in the southern Labrador–northeast Newfoundland area; the other main predators take their turns later. In each year, therefore, the numbers of adult capelin may be considerably reduced by harp seals before man comes strongly into the picture. Thus, the capelin situation has some of the characteristics of a gauntlet fishery.

If the harp seals are being harvested by the fishermen, the capelin could be considered to be utilized by the seal to help provide a seal fishery for the fishermen.

As described above, the main fishery for capelin takes place as they mature, when they are generally about three years old. They are also subject to heavy predation by various predators at this time. Nothing seems to be known, however, about the extent to which seals feed on younger capelin, since there are no data on the sizes of capelin eaten by seals.

Atlantic Herring

Harp, harbour and, probably, grey seals are all predators on Atlantic herring stocks. Predation by harp seals is important in the southern Gulf of St. Lawrence, but estimates of the amount consumed cover a fairly wide range.

The discrepancies in estimates of the amount consumed by harp seals between those calculated from the believed size of the herring stocks and those calculated from the seal population have been discussed earlier. If the former estimates are more nearly correct, the consumption would have been about 7000 t in 1970, when the herring stock was about five times as large as it is at present. Consumption of herring is therefore likely to be considerably less at present. Calculated from the seal population, consumption at the same period was about 21,000 t. However, even if this estimate is correct, it seems likely that current consumption of herring would be reduced as the declining herring stock forced the seals to turn to other prey.

Predation on herring by harbour seals seems to be most important in NAFO Area 4WX (Area F) round Nova Scotia. In a previous section current consumption of herring by harbour seals in this area was estimated at 2,000t –2,900 t. This estimate can be compared with the 1983 catch (81,000 t) and the estimated biomass in the same area (335,000 t). Seal consumption does not seem to be of any great significance in this area.

Pacific Herring

Pacific herring are subject to significant predation by harbour seals, northern fur seals, Steller sea lions and California sea lions. The rounded estimates of consumption developed above are:

Harbour seals	6,500 t
Northern fur seals	2,000–3,000 t
Steller sea lions	5,500–8,000 t
California sea lions	3,000 t
Total estimated consumption	17,000–20,500 t

As noted earlier, the harbour seal figure seems likely to be an underestimate.

Shrimp

It is known that shrimp of various species figure largely at times in the diet of harp seals, probably particularly in the northern part of the seals' range. Northridge (1986) points out correctly that if all the consumption is of the main commercial species (*P. borealis*), a major discrepancy appears, in

that such tentative estimates as can be made of the amount of shrimp consumed appear to be much too large when compared with present estimates of the size of the shrimp stocks. Other species of shrimp, however, such as *P. montagui*, also appear in the stomach contents of harp seals (Sergeant, 1973, 1976) and this will tend to reduce the discrepancy. At present very little is known either about the feeding habits of the seals or about the distribution and abundance of the shrimp, but at the upper extreme, the impact of harp seals on the commercial shrimp fishery could be quite substantial, although it could equally well be very small. Further studies of harp seal diet at appropriate times and places should help to narrow this wide range of possibilities.

Salmon

Predation by seals on salmon attracts considerable attention from both the public and the fishing industry. This attention is probably rather out of proportion to the actual quantities of salmon removed and is stimulated both by the value of the fish and by the fact that the depredations, which take place as salmon enter narrow waters on their spawning migrations, are relatively conspicuous.

On the Atlantic coast, the grey seal seems to be the only species recorded as taking salmon, although from its behaviour elsewhere, it would be expected that the harbour seal would also feed on salmon occasionally. There are no data to indicate what proportion of grey seal food is composed of salmon, but this species does not appear to be a major component. The estimate of total food consumption by grey seals is about 240,000 t. Current commercial salmon catches are around 1,000 t–2,000 t. Thus if salmon were only 0.4%–1% of the food of the grey seals, their consumption would equal the catches. Such a low proportion is impossible to estimate with any precision from direct observations of occurrence in the diet. Northridge (1986) refers to evidence which suggests that the amount of predation on salmon by grey seals may not vary much with changes in seal abundance. Since the Atlantic salmon fishery is now much restricted and actually closed on some rivers, the effect of grey seal predation may be greater on the spawning run than on the catch.

On the Pacific coast, the various species of salmon are eaten by harbour seals, northern fur seals and Steller sea lions; consumption by California sea lions is probably relatively unimportant. The very tentative estimates of the amount taken by the various predators are:

Harbour seal:	6,000 t, mainly in the inlets and lower parts of rivers;
Northern fur seal:	1,000 t–1,400 t and possibly higher (Northridge 1986), mainly offshore but some in the inlets;
Steller sea lion:	2,700 t–3,600 t, mainly where rookeries and hauling-out places are adjacent to major salmon runs.

These estimates may be compared to an average catch, for 1973–1982, of 64,000 t for all Pacific species of salmon combined (Canada, DFO, 1984b).

Demersal Fish

Bottom-dwelling, or demersal, fish of various species form a significant part of the food of several species of seals. The proportions of the various species within this group will vary seasonally and with locality; the small size of most of the samples of seal stomach contents examined will also cause relatively large random variations in the proportions recorded. Observations of the proportion of demersal fish as a group will, therefore, be more reliable and consistent than those of the individual species. Similarly, it is the demersal fish as a group that are the target of many trawl, and some line and net, fisheries, although, again, there are local and seasonal variations. It will therefore be most useful to compare estimates of seal consumption and catches, and to try to assess possible impacts, for the demersal fish as a whole, rather than for individual species.

Harp seals feed on demersal fish to a small extent when they are in their southern range. The summarized data in Table 24.1 show that of 555 stomachs containing food, a minimum of 39 (7%) and a maximum of 66 (12%) contained demersal fish. (The high figure makes the unlikely assumption that all 27 stomachs containing "unidentified food" contained demersal fish.) Since it is not possible to convert percentage occurrences to actual proportions in the food with any accuracy, the proportion of demersal fish in the weight of food eaten by harp seals will be taken as 7%–12%. This proportion must have wide confidence limits, but the evidence suggests that it is much smaller than the proportion of capelin.

Hooded seals appear to take a much larger proportion of demersal fish than do harp seals. No data are available for Canadian waters, but the Greenland data in Table 24.2 show that a minimum of 649 and a maximum

of 1,175 stomachs contained demersal fish out of 1,341 with food; this represents a range of 48%–88%. The individual samples show ranges of 31%–90% (south Greenland), 94%–97% (southeast Greenland), and 75%–81% (northwest Greenland). In this species, it seems likely that much of the unidentified or unspecified fish was of demersal species, so that the true value is towards the upper end of the range. A range of 70%–90% will be used in future calculations.

Harbour seals on the Atlantic coast feed on a wide range of fish and invertebrates. The data in Table 24.3 show about 30% of the stomach contents consisting of commercially important demersal species, but again, the confidence limits must be wide. On the Pacific coast, the proportion of demersal fish is probably lower, on account of the greater extent to which both salmon and herring are eaten, but the amounts taken of bottom-living fish like lingcod, flatfish and hake are still significant (Spalding, 1964).

In a previous section it was stated that commercially important species, including a large proportion of demersal fish, were consistently recorded in the stomachs of grey seals in the North Atlantic, including Canadian waters. It was considered likely that the overall proportion of commercial species in the diet of grey seals was in the range of 60%–90%, and that about 70% of those were demersal species, that is, about 42%–63% of the total food. In addition, an unknown, but possibly small, proportion of the food of grey seals will consist of sand lance, which are the subject of important fisheries in some parts of the Atlantic area, although they are not fished at present in Canadian waters.

The northern fur seal, at least in Canadian waters, seems to feed largely on pelagic and mid-water species. All the types listed in Table 24.6 as important in B.C. waters fall into this category, although some, such as the rockfishes and walleye pollock, are important to commercial trawl fisheries elsewhere. Consumption of demersal fish by northern fur seals in Canadian waters can thus be ignored.

Both species of sea lion apparently feed principally on herring in B.C. waters, but the data reviewed earlier suggest that demersal species, particularly dogfish and hake, are also important. The combined consumption of these species by Steller sea lions is estimated at 5,400 t–7,200 t, about 30% of a total consumption of 19,000 t–26,000 t. The California sea lion visits the B.C. coast only during the winter, when herring are abundant; other species, including the demersal fish, may therefore form a rather smaller proportion of their food, perhaps 20%–30% out of 6,000 t, or 1,200 t–1,800 t.

These estimates of consumption of demersal fish are summarized in Table 24.12.

Table 24.12
Estimated Consumption of Demersal Fish

Species	Total Consumption (000s t)	% Demersal	Demersal Consumption (000s t)
Atlantic Coast (areas C–F)			
Harp seal	1300	7 – 12	90 – 155
Hooded seal	500	70 – 90	350 – 450
Harbour seal	17	30	5
Grey Seal	240	42 – 63	100 – 150
Total			540 – 760
Pacific Coast			
Harbour seal	54 – 72	20	10.8 – 14.4
Northern fur seal	5 – 7	–	–
Steller sea lion	19 – 26	30	5.4 – 7.2
California sea lion	6	20 – 30	1.2 – 1.8
Total			17.4 – 23.4

For comparison purposes the combined catch of hand- and longlines, Danish and Scottish seiners and otter trawlers on the Atlantic coast averaged about 630,000 t in 1981/82 (Canada, DFO, 1984a). This figure is of about the same order of magnitude as that for the consumption of demersal fish by seals, though there are important differences in the areas (the seal consumption is generally further north) and in species composition (the commercial catches will contain a higher proportion of cod).

On the Pacific coast in 1981, the combined landings of the principal species of groundfish (lingcod, Pacific ocean perch, Pacific cod and soles) amounted to about 17,000 t; this figure, again, is of about the same order of magnitude as that for the consumption by seals.

As Table 24.11 shows, Atlantic cod are the most important demersal fish to the east coast Canadian fishery, forming about 40% of the total catch. They are sometimes reputed to be a major food of harp seals, but the data do not support this view. Only four harp seals have been recorded as containing cod, and in general harp seals seem to prefer smaller prey. Grey seals feed extensively on demersal fish of rather larger sizes. Table 24.4 shows that cod form about 13% of the occurrences of commercial fish in the data of Mansfield and Beck (1977). Their weighted calculations indicate that cod constitute 14% of total food consumption, which might be equivalent to about 20% of the commercial species in the diet. Mansfield and Beck also note that grey seals feed on cod when the fish are making their inshore migration in the spring. Cod have been recorded, however, as forming up to 49% of the food from some localities in the United Kingdom, with an average of a little under 20% (SMRU, 1985).

There are no useful data on the food of hooded seals in Area C. Since this seal feeds extensively on large demersal species, cod may form a significant part of its diet although it has only been recorded in small numbers in the Greenland data (Table 24.2). A tentative estimate of cod consumption by seals could be based on the assumption that they form the same percentage of the demersal fish eaten by hooded and grey seals as they do of the commercial demersal catches, and on ignoring any consumption by harp seals. This calculation yields an estimated consumption of about 200,000 t–280,000 t. In recent years the estimated biomass of cod in Areas C to F has been over 2 million t (Northridge, 1986). The combined catches have been in the vicinity of 500,000 t, about twice the tentative estimate of the amount consumed by seals.

Redfish are a deep-water species and it is unlikely that they figure to any great extent in the food of grey or harp seals. They may be considerably more important in the food of hooded seals, and formed about 10% of the occurrences in the Greenland samples (Table 24.2). If this figure is applied to the estimated total consumption by hooded seals in Area C, it gives an estimated consumption of redfish of the order at 50,000 t. The total Canadian landings of this species in 1983 were 58,000 t (Northridge, 1986).

Flatfish of various species are recorded from time to time in the stomachs of grey and harbour seals, and occasionally in harp seals. The data are scanty, but both for Canada (Tables 24.3 and 24.4) and the United Kingdom (Table 24.5), they are consistent with the hypothesis that flatfish form 5%–10% of the food of harbour and grey seals. This leads to a tentative estimate of total consumption in Areas C to F of 12,000 t–25,000 t. Recent Canadian flatfish landings (1982) from Areas C to F have amounted to about 110,000 t (NAFO, 1984). Northridge (1986) estimates the consumption of flatfish by harbour seals in the Maritimes at about 2,000 t. Of this amount, about 1,000 t was taken in NAFO Division 4VWX, which is about equal to recent landings from the area. Canadian fishermen have recently been catching a wider range of species of flatfish, and this may tend to increase the level of competition between them and the seals.

A special case among the bottom-living fish is the sand lance. This species is the subject of specialized fisheries in some European waters, where it is locally abundant and is also, apparently, subject to heavy predation by grey seals under similar circumstances. SMRU (1985) reports it as forming between 15% and 80% of the diet of grey seals in four localities round the British Isles (Table 24.5). The sand lance, however, forms only a small percentage in data from Iceland (Table 24.5) and only 1% of the Canadian occurrences listed in Table 24.4. The Royal Commission has, however, been informed (Harwood, 1985; Stobo, 1986) that in the vicinity of Sable Island grey seals feed heavily on sand lance. It is not possible to assess what proportion of the food of Canadian grey seals as a whole consists of sand lance, although the fish may be locally important.

Other Pelagic and Mid-Water Species

The pelagic species most frequently eaten by seals in Canadian waters are capelin and herring, and these have been discussed in preceding sections. On the Atlantic coast a variety of other pelagic species are eaten in small amounts by harp and harbour seals, but grey and hooded seals eat very few pelagic fish. The principal species consumed is probably mackerel. On the Pacific coast the northern fur seal seems to feed almost exclusively on pelagic species. Its consumption of salmon and herring has already been discussed, and Table 24.6 suggests that it also eats significant amounts of sablefish. If the proportion of this latter species is similar to that of salmon or squid, the amount consumed may be of the order of 1,000 t as compared with 1982 landings of about 7,000 t (Canada, DFO, 1984a).

Squid form significant components of the diet of harbour seals on the east coast and of northern fur seals in the Pacific, but it is not possible to make any useful comment on the amounts eaten in relation to the size of the stocks or of the commercial catch.

Effects on Commercial Fish Stocks and Catches

General Principles

Previous sections have reviewed such data as are available on the amounts of commercial fish consumed by seals, and have made some comparisons with the biomass of the fish stocks and with the present levels of catch. The next and critical questions are: What effect has seal predation on the size of the commercial catches, and how will these effects change if the size of the seal population alters? Virtually no direct observations have been made which can provide guidance as to the effects to be expected, and long-continued large-scale experiments would be necessary to provide useful results. It is necessary, therefore, to have recourse to a theoretical approach founded on the basic biological principles involved.

It may be noted that the approach followed is very similar to that involved in assessing the impact of commercial fisheries on fish stocks, and especially the interactions between the impacts of two or more fisheries on the same species. The two types of study involve making similar assumptions, for example about the response of fish stocks and their predators to change in the mortality rate of the fish stocks, which may never be precisely fulfilled. Nevertheless, the fishery assessments have provided useful bases for taking policy decisions concerning the management of fisheries. The Commissioners believe that the same is true in relation to the interactions between seals and fisheries.

The problems which arise are very complex, and even in an ideal situation where it is known exactly how many fish of each sex at each age were in the stock, and how many were eaten by the seals, it would still be impossible to achieve precise results unless it was also known what the fishery took, how the fishery would respond to any change in the abundance of the fish, and how the recruitment of young fish to the stock would be affected by such changes. Knowledge of the size and structure of the commercial catch is relatively good for most of the commercial fishes, and for those which have been most studied (e.g., salmon and Atlantic cod) a consid-

erable amount is known about the size and structure of the population, although relatively little is known about the effect of stock size on recruitment to fish stocks. It is inadequate knowledge of the amount and size and age-composition of fish consumed by seals which most hampers attempts to assess the impact of seal predation on commercial fish catches.

In developing a theoretical study of the problem, the most simplistic approach would be to consider that any fish that were not eaten by seals as a result of a reduction in seal numbers would subsequently be caught by fishermen, so that the increase in commercial catch would equal the amount previously eaten by seals. Conversely, on this basis, if the amount eaten by seals increased by a certain amount, then the catch would decrease by the same amount. There are a number of reasons why this simple approach usually leads to incorrect conclusions; the changes in seal consumption and in catch will be equal only under certain special conditions.

In the first place, not all the fish which would have been eaten by seals would be caught if the seals were removed; a proportion will die from other causes, so-called "natural deaths". This well-known aspect was discussed by Dr. S.J. Holt in his submission (Holt, 1985), and as he pointed out, the actual change in catch produced by a change in consumption by seals will depend on the rates of fishing, consumption by seals and natural mortality. The higher the fishing mortality rate compared to the natural mortality rate, the larger will be the proportion of the seal consumption which would be transferred to the catch if the seals were removed.

Put simply, if a fish which might have been eaten by a seal today is not eaten, perhaps because the seal has been killed in a culling program, it will still die ultimately. It may die from natural causes, such as old age, disease or being eaten by a shark, or it may be caught by a fisherman. Assuming that it is a typical member of the population, the chance of its being caught and thus added to the yield of the fishery depends on the relative rates of mortality deriving from fishing (F) and from natural causes (M). A simple model (Appendix 24.1) shows that, if as a result of a change in the seal predation rate, the numbers of fish caught and the numbers consumed by seals change from C and H to C' and H', the proportion of the amount of fish no longer eaten by seals ($H - H'$) which is now added to the catch ($C' - C$) is given by:

$$R = (C' - C) / (H - H') = (F/M) / (1 + F/M) \ ,$$

$$\text{or} \ \ R = F / (F + M) = E \ ,$$

where E is often referred to as the exploitation rate.

Thus R depends only on the relative magnitudes of the fishing and natural mortality rates and is not affected by their absolute value or by the rate of predation by the seals. The following table illustrates how this effect would operate:

F/M	R
0.2	0.17
0.5	0.33
1.0	0.50
2.0	0.67
5.0	0.83

These simple calculations do not allow for the fact that typically, fish are growing over the period during which they are subject to seal predation and to the fishery. If a fish is not eaten by a seal because that seal has been killed, but is subsequently caught by a fisherman, it will be older and therefore probably larger than it would have been if the seal had eaten it. These calculations will therefore underestimate the impact of the seals on the fishery in terms of weights.

This effect was considered by the International Council for the Exploration of the Sea's (ICES) ad hoc working group (ICES, 1979), and the group proposed a formulation similar to that shown above. Using our symbols and extending the ICES equation for the total life span of the fish, the equation becomes:

$$R = (F/M) / (1 + F/M - G/M)$$

where G is the instantaneous growth rate of the fish. It is obvious from this relationship that the effect of allowing for growth is to increase the value of R. If G were greater than M, then the amount added to the catch would be greater than the amount eaten by the seals.

One weakness in this model, as expressed in the equation above, is that it assumes that the fish continue indefinitely to grow at a constant instantaneous rate, whereas the growth rate of nearly all fish slows down as the fish get older. More realistic forms of this model would include other expressions for the growth of fish.

In general, G is greater than M in young fish, but decreases as the fish get older, and there is a critical age (Ricker, 1975) at which G equals M, and the biomass of a year-class would, in the absence of fishing, be at maximum. For most commercial fish, especially demersal fish, fishing starts before the critical age. If fishing is heavy so that older, slow-growing fish form only a small part of the population, the average G will be greater than M so that R will be greater than 1.0.

This model does not make it possible to examine the effects that would arise if seals ate older or younger fish than those caught in the fishery, a complication which becomes important if growth rate can vary with age. These problems can be overcome by using an age-structured population model which incorporates the growth of the fish and permits the separation of mortality due to fishing, seal predation, and other natural causes.

It is common practice in such models to use the von Bertalanffy growth curve (Beverton and Holt, 1957), which provides for a gradual decline in growth rate with age. Three models using this relationship have been developed to examine the relation between catch and the amount of fish consumed by seals. One such model is presented in Appendix 24.2, and two others in Northridge (1986). Other models using different growth functions could easily be developed, but since the shape of the growth curves would have to resemble the same natural curves, they would give similar results.

The curves in Appendix 24.2 show the results of a preliminary study of how the increase in yield to the fishery, following cessation of predation by seals, would compare with the quantity of fish removed by the seals. It is assumed that recruitment to the fish stock remains constant.

The results show that the ratio of the gain in catch to the removals by seals is affected not only by the intensity of the fishery and of the seal predation, but also by the respective ages at which the fishery and the predation begin to operate. In general terms it appears that:

- The relative gain increases as the fishing intensity increases.
- The relative gain tends to increase as predation intensity increases, particularly when fishing intensity is high.
- The relative gain is greater when the predation starts earlier than the fishery.

The examples make it clear that the gain to the fishery may be either greater or less than the quantity of fish taken by the seals. The relation depends on the relative mortality rates due to the fishery, to seal predation and to natural causes, and on the ages at which fish become susceptible to fishing and predation. In example B, where fishing mortality begins at age four and seal predation at age two, the gain becomes greater than the seal removals when the fishery is fairly intense, with an F of about 0.4 or more, and this level of intensity is typical of a number of major fisheries.

Other expressions for the growth of the fish could be used in these models, but they would all lead to similar general conclusions: particularly, that making allowance for growth increases the potential benefit to the fishermen of reducing seal predation.

Northridge (1986) has developed two other computer routines, based on rather similar models, to examine other aspects of the problem. The first model (Northridge, 1986, Appendix) is a yield isopleth model based on the Beverton and Holt (1957) yield equation. This model shows how the weight of the catch from a fixed level of recruitment to the fish stock and with a known level of predation by the seals will vary with the fishing intensity and the size of the fish at first availability to the fishery. This model can be used, for example, to examine how the fishing intensity would have to be changed to maintain the catch at the same level after a change in the rate of seal predation. Comparison of Northridge's (1986) Figure 4 with his Figure 5 shows that, for this particular model and set of parameters, which correspond to those of the Division 2J3K cod stock, when the seal predation rate is doubled, the fishing mortality rate F has to be increased from about 0.2 to over 0.5 to maintain the catch at the same level (250 units). Alternatively, if F remained the same – and this is perhaps a more likely situation – the maximum catch for $F = 0.2$ would drop from 250 to 200 units.

In his second approach Northridge (1986, Appendix) has used a population model similar to that in Appendix 24.2 to develop simulations to show how the catch and the seal consumption will change over time. These simulations can allow for random variations from year to year in the amount of recruitment, and it is possible to set this variability at levels based on actual observations of fish stocks. The simulation also allows the rate of seal predation to be changed during the run so that the possibility of detecting any resulting change in yield in the presence of variable recruitment can be examined.

In applying all these models to examine the effects of consumption by seals on the catches from stocks of fish, a number of assumptions have to be

made. These assumptions, which will be more or less justifiable in many situations, include:

- that a change in the rate of predation by seals would not change the rate of natural mortality from other causes. This assumption might break down if a significant change in fish abundance resulted from the change in the predation rate.

- that the seal predation is evenly spread over the population.

- that seal predation rate (i.e., the proportion of the fish stock taken by seals) is independent of fish density. This may be in error in either direction; if a particular fish species becomes scarce, seals might tend to move in search of more abundant species; on the other hand, if a fish stock becomes locally very dense, the seals might need a smaller proportion of it to satisfy their food requirements.

- that fish growth rate and recruitment rate are not density dependent.

In applying approaches such as these to determining the impact of seal populations on fish stocks, it is also necessary to make assumptions concerning the relation between the mortality rate due to seal predation and the number of seals in the population. At the present time it does not seem justifiable to adopt any hypothesis other than the simple one that predation rate is proportional to the number of seals. These and other factors which may affect the extent of the impact of seal predation on commercial fish catches are discussed in more detail later in this chapter.

The foregoing discussion deals with situations in which predation by seals and commercial fishing both operate over an extended period during the life of the fish, and there is generally some degree of overlap between them. A rather different kind of situation exists where both seals and fishing operations intercept migrating fish at a strategic point on their return journey, the so-called "gauntlet fisheries". Pacific salmon provide the most important example of this situation in the present context. There is little concrete evidence at present of a similar situation with regard to Atlantic salmon.

In such cases, natural mortality can probably be ignored for the duration of the fishery. The fish no longer eaten by the seals would now partly be caught in the fishery and partly escape to spawn. Thus the gain in the number caught will always be less than the original seal removals.

Growth also can probably be ignored so that the proportional gain will be the same for either the number or the weight of the catch.

A fairly simple formulation is possible if it is assumed that the seal predation and fishery operate simultaneously for a time, and that any fish which have not been caught by either constitute the escapement. It is shown in Appendix 24.3 that if N is the total run, C is the catch, H is the removal by seals, and E is the escapement, then, in the absence of seals, the new escapement E' is given by:

$$E' = N^{H/(C+H)} E^{C/(C+H)}$$

The new catch is then given by:

$$C' = N - E'$$

In a hypothetical example when $E = 200$, $C = 600$ and $H = 200$, then $E' = 299$ and $C' = 701$, so that the proportion of the seal take which has been added to the catch is 101/200 = 50.5%.

If the seal removal is made relatively small by putting $E = 2{,}000$, $C = 6{,}000$ and $H = 200$, then the relative addition to the catch becomes 107/200 = 53.4%. If the catch is reduced in this model to 4,000 out of the same total population, the relative addition becomes 61/200 = 30.5%.

In the above analysis it is assumed that the amount of fishing effort is kept constant, as seems appropriate in considering many pelagic or demersal fisheries. In some gauntlet fisheries, however, such as those for Pacific salmon, it is possible to monitor the actual escapement, and there is also excess fishing power available which, under regulation, is only employed for a restricted period. In such cases it may be possible to adjust fishing effort quickly so as to keep escapement to the desired level, and when this occurs, much, or all, of the additional fish becoming available through reduced seal predation might be added to the catch.

Size Effects

The analysis given in Appendix 24.2 assumes that the mortality rates due to fishing (F) and from predation by seals (S) are constant above a certain age, and in the first instance that both mortalities operate over the

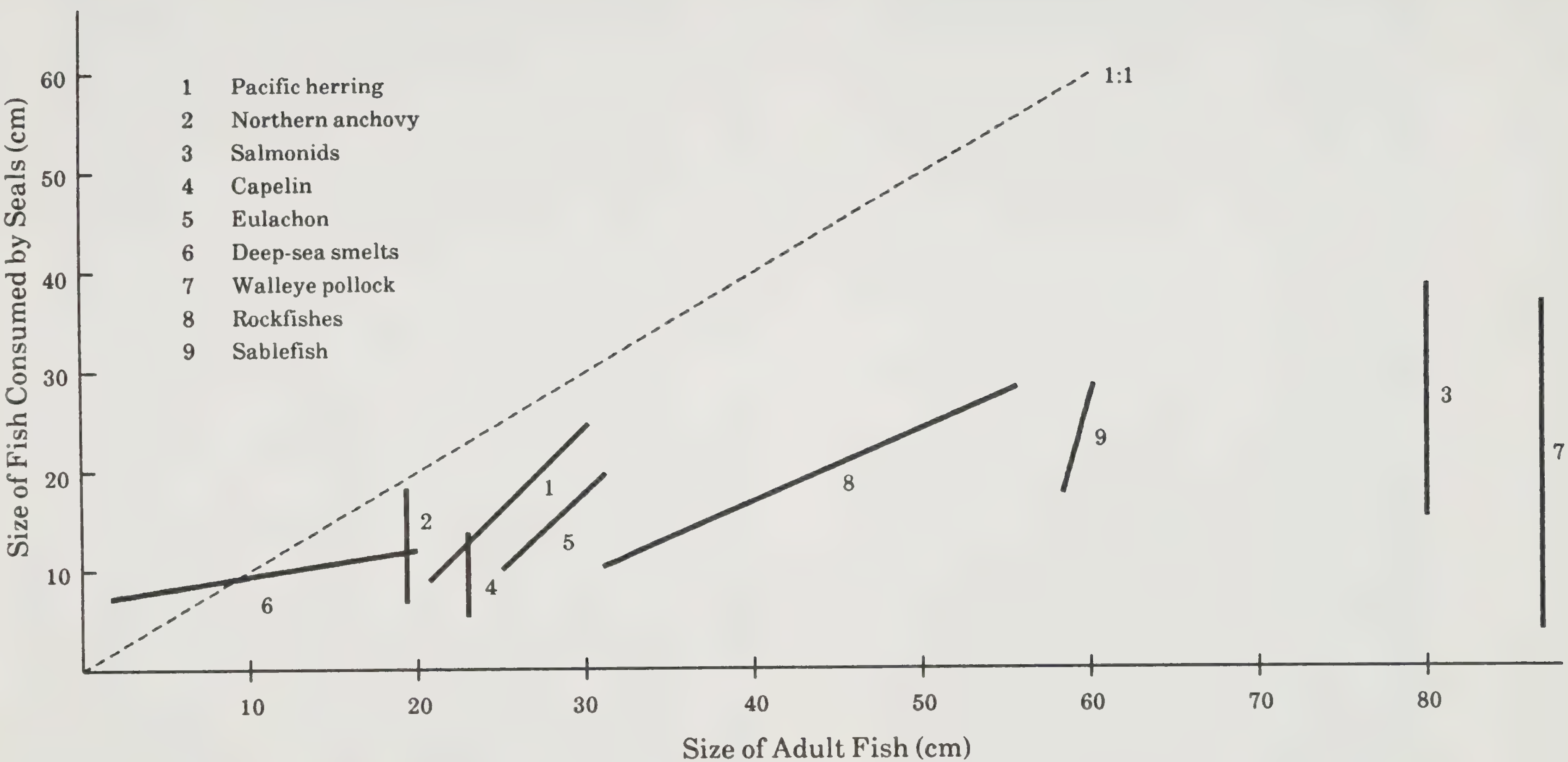
same range of ages. More complex models show that the ratio R will vary if seals and fishermen take different sizes of fish. If seals include in their diet fish smaller than those taken by the fishery, this will tend to increase the impact on catches of a given weight consumed; this means that R will increase. The extent of the difference, if any, between the age of recruitment to the fishery and age at first consumption by seals will depend both on the sizes of fish which particular species of seals normally prefer and on the size to which each species of fish grows. In general, it is likely that the larger species of seals (e.g., grey, hooded and male fur seals, and sea lions) eat larger fish than do the smaller seals (e.g., harp, harbour and female fur seals). Spalding (1964), for example, showed that large species of fish (those with a mean adult length of 25 cm or more) formed a larger proportion of the food of sea lions than did smaller species (with a mean adult length of less than 25 cm), whereas the reverse was true of the harbour seal.

It also seems likely that, in general, any differences in age (or size) between fish eaten by seals and those caught by commercial fishermen, will tend to increase with the size to which the fish normally grows. Fish whose normal adult size is not much greater than the size first taken by seals are likely to show little difference, but fish whose adult size is much greater than that first taken by seals will probably show a substantial difference. The only extensive comparison of the "normal adult size" of a variety of fish species with the sizes eaten by seals has been published for migrating fur seals (females and young males) off the North American coast by Perez and Bigg (1985). The data in their Table 4 are summarized in Figure 24.2; the line for each species of fish joins the point of minimum size in seal stomach and minimum adult size with the point for the maximum ends of both ranges. It is evident that for these seals, the preferred food range is about 10 cm–30 cm, and that above an adult length of 15 cm–20 cm there is an increasing difference between size consumed and adult size as the latter increases. In most fisheries, the size mainly taken would correspond fairly closely to the adult size range, which implies that in the larger fish species, seal consumption would normally start at an earlier age than would the commercial catch.

The grey seal is larger than the female fur seal and appears generally to feed on larger fish when these are available, although, as has been mentioned earlier, it does take the relatively small sand lance in large quantities when that species is abundant. In some localities grey seals feed extensively on cod, which are recorded as forming about 50% of its diet at the Farne Islands and the Isle of May, off the east coast of the British Isles (SMRU, 1985).

Figure 24.2

Relationship Between Size of Adult Fish and Size Consumed by Northern Fur Seals



Source: Perez and Bigg (1984, Table 4).

Note: The line for each species joined the point representing the lower ends of both ranges with the point representing the upper ends of both ranges.

The mean weights of cod in the seal stomachs in these areas are stated as 1,050 g and 450 g respectively. These amounts are less than the average weight of cod in commercial catches, indicating that seals feed on cod younger than those taken in the fishery. Failure to allow for this in the model would lead to underestimates of the impact of predation on the fisheries.

If the larger species of commercial fish can grow fairly rapidly to sizes at which they are less vulnerable to attack by seals, this also could have a significant effect on the impact of seal predation on commercial catches. As an example, tests with a model having similar parameters to the North Sea cod stock referred to above showed that with seal predation starting at age one and the fishery at age two, the effect of a given seal consumption on the catch was nearly twice as great ($R = 1.4$) if seal predation extended only to age four, than it was ($R = 0.8$) if predation, like the fishery, took cod of all ages over the critical point. The effects are complex, however, and a specific analysis would be necessary for any case for which adequate data were available.

Application to Particular Species

The following sections apply these general principles and mathematical techniques to the principal groups of prey species. Rather than carry out a detailed presentation, describing the impact of any given change in seal consumption on fish stocks and commercial fish catches, the results have been summarized in terms of the likely ratio, R, of the change in catch to the change in amount consumed by seals. This method will take explicit account of the mortality rates due to fishing, seals and other causes, and of the growth of the fish. It is subject to the assumptions discussed earlier (e.g., that the fish consumed by the seals are, in other respects, typical members of the fish population). This procedure is probably valid (subject to the validity of these assumptions) for small changes in seal consumption, but may be less valid for large changes when second-order effects (e.g., compensatory changes in other causes of mortality) may become significant. The model assumes, however, that the mortality rate due to natural causes other than seal predation (M in Appendix 24.2) remains unchanged if seal predation is reduced. In other words, the fish not now eaten by seals are shared between the fishery and the other causes of mortality in the same ratio as before the seal stock was reduced. This means that the number of fish dying from these causes will increase. This, in turn, might require an increase in the numbers of other competing predators.

It may be noted that the presentations in this chapter concern the total impact of the stock of a given species of seal on fish catches; that is, the theoretical increase that would occur in fish catches if all the seals of that species were to disappear or to give up eating commercial species of fish. This hypothesis has some convenience for the purposes of presentation, but it has no practical significance. Further, large changes in consumption, fish stocks and fish catches would theoretically be involved, and several of the assumptions involved in the calculation of the ratio R may well break down. Chapter 29 on population control examines the more realistic question of what would happen to fish catches if there was a small or moderate change in seal consumption, or if a potentially expanding population were held stable. As used there, assumptions used in calculating R are more likely to be satisfied. In other words, the figures of total impact presented here should be treated with some caution, but the figures for the effect on the impact of the smaller population changes used in the population-control chapter are likely to be more reliable.

Capelin

Pauly (1980) gives estimates of the natural mortality rate (M) and the von Bertalanffy growth exponent (K) for capelin in the Labrador area as 1.3 and 0.48 respectively. Northridge (1986) suggests that total allowable catches (TACs) of capelin have been calculated as 10% of initial biomass, and with $M = 1.3$, the implicit value of F is 0.19. Recent catches have been small, however, and the current value of F is much less than this. In an earlier section it was stated that seal predation is likely to be between 1% and 5% of total predation; ignoring natural mortality from causes other than predation, this implies that the rate of seal predation mortality (S) is in the range of 0.01 to 0.06 and that, correspondingly, the non-seal mortality rate (M') is in the range 1.3–1.2. These values of K, M', F and S can be used in the formula developed in Appendix 24.2 to obtain an estimate of R. It is also necessary to give values to T_r, the age at which the fish are first taken in the fishery, and T_s, the age at which they are first subject to seal predation. Some results are given in the table on the next page.

A central value of 0.10 will be used in the following calculations which corresponds approximately to $F = 0.1$ or about half the value believed to be required to yield present TACs. Under the present low intensity of the capelin fishery, however, this may still lead to an overestimate of the impact of seal predation on current catches.

T_r	T_s	F	0.05	0.10	0.19
		M	1.20	1.20	1.20
		S	0.04	0.04	0.04
2	1		0.06	0.11	0.19
2	2		0.05	0.10	0.17
3	2		0.04	0.09	0.16
3	3		0.05	0.09	0.15

Atlantic Herring

The principal seal predator on some east coast herring stocks is the harp seal, although herring are also eaten by harbour seals and grey seals. The main predation by harp seals is in the southern Gulf of St. Lawrence, and the same model can be used to examine what effect the removal of a given quantity of Atlantic herring by seals in this area would have on the commercial catch. Following Northridge (1986) for the value of the parameters, we have both seals and the fishery beginning to take herring at age two, the fishing mortality rate (F) of 0.3, and the von Bertalanffy exponent (K) of 0.616. The value of the total natural mortality rate (M) for herring varies from stock to stock over a range of about 0.2–0.4 (Pauly, 1980). The proportion (R) of the change in seal predation which will appear in the catch then depends on how much of total natural mortality is the result of predation by seals. The following table shows R for S forming different proportions of the total mortality, S being the mortality rate due to seal predation:

S/M	$M = 0.2$	$M = 0.4$
0.05	0.75	0.55
0.25	0.83	0.63
0.5	0.94	0.77

It appears that in the case of the Atlantic herring, a change in the amount consumed by seals is likely to produce a slightly smaller change in the amount of the catch. A value of 0.7 will be used for R in subsequent calculations.

The consumption of herring by harbour seals takes place mainly in a different area (4WX) and on a different stock from that by harp seals. It was estimated in a previous section at about 2,000 t –2,900 t against a biomass of 335,000 t and a catch of 81,000 t. The ratio of catch to biomass suggests that the value for F for this stock is not unlike that for area 4T, and in this case it is again likely that any change in seal consumption will cause a slightly smaller change in the catch. Since, however, seal consumption seems very small here compared to the catch, the effect of, for example, a 25% increase or decrease in the seal stock would have much less visible effect on catches in 4WX than a similar change in area 4T.

Pacific Herring

Since 1972, the pre-season biomass of herring on the British Columbia coast has averaged about 900,000 t, and the average catch has been about 50,000 t (Haist et al., 1985). Pauly (1980) gives values of K and M for the Pacific herring in B.C. waters of 0.48 and 0.50 respectively. The estimates of biomass and catch suggest that F is about 0.075. Since the seal consumption seems likely to be about half this, S can be taken as about 0.04, and the natural mortality rate from other causes as 0.46. These values can be used in the Appendix 24.2 model. The result shows that the change in catch is 18% of the change in seal consumption. This figure is almost totally insensitive to the rate of consumption by seals; it increases slowly with the rate of fishing mortality and reaches about 40% if F is 0.20, which seems an improbably high value. The model is also not very sensitive over a reasonable range of ages at which seals and the fishery begin to take fish; in the above calculations these ages were taken as two years and three years respectively. Reduction in the natural mortality rate, excluding seals, tends to increase the value of R, but only slowly.

The above estimate is based on the assumption that the fishing pressure would remain constant if seal predation changed. However the Pacific herring fishery in Canada has been managed in recent years with the aim of maintaining a fairly constant spawning stock. If this policy were continued, it would allow an increase in fishing pressure if seal predation were reduced, and consequently the catch would increase by a proportion greater than that calculated on the assumptions of the Appendix 24.2 model; that is, R would move towards 1.0.

Salmon

Much of the seal predation on the various salmon stocks takes place at about the same time as the fishery, and in this case the model described in Appendix 24.3 can be applied. The ratio between the catch and the desired escapement can vary greatly among different salmon stocks, depending on the species, on environmental factors and, particularly, on the size of the spawning run relative to the optimum level. The optimum escapement can range between a small fraction of, and several times the amount of, the acceptable catch. Using the above catch and seal-consumption figures with escapement/catch ratios of 0.2, 1.0 and 2.5 (which do not fully cover the range of possible values), the corresponding proportions of consumption transferred to catch are 38%, 70% and 84%. Thus, while reduction in seal consumption should, on this model, lead to an increase in catch, the amount of the increase will be less than, and possibly less than half of, the amount of the reduction. We have already noted, however, that where it is possible to adjust the fishing effort in these highly regulated fisheries to keep the spawning escapement at the desired level, virtually all the saving on seal predation will be transferred to the catch.

Demersal Fish

There is considerable variety in the growth and mortality rates of demersal fish, not only among species but also among stocks within species such as cod. It is not possible, therefore, to carry out more than indicative calculations of appropriate values for this group.

In making these calculations, a value of 0.2 has been used both for total natural mortality rate (*M*) and for the growth exponent (*K*). Results tabulated by Pauly (1980) suggest that these values are central to the commonly reported range for both gadid fish (e.g., cod) and flatfish. Other factors to be taken into account are the ages at which the fish enter the fishery (T_r) and at which they become subject to predation by seals (T_s), the amount that seal predation contributes to total natural mortality, and the fishing mortality rate.

The following table summarizes the values of *R* for a number of combinations of these parameters:

T_r	T_s	S/M	0.25	0.75	0.25	0.75	0.25	0.75
		S	0.05	0.15	0.05	0.15	0.05	0.15
		M'	0.15	0.05	0.15	0.05	0.15	0.05
		F	0.10	0.10	0.20	0.20	0.30	0.30
2	1		0.89	1.76	1.32	2.20	1.57	2.35
2	2		0.76	1.40	1.11	1.78	1.29	1.85
4	2		0.76	1.46	1.10	1.79	1.29	1.89
4	4		0.60	1.08	0.86	1.30	0.98	1.35
6	4		0.59	1.08	0.84	1.31	0.97	1.38
6	6		0.52	0.88	0.73	1.09	0.84	1.13

The value of S/M of 0.75 is probably much higher than will occur in nature, but it is included here to illustrate the effect that increasing the proportion of seal predation in total mortality has on the value of R; that is, on the impact on the fishery.

The range of R is generally from 0.5 to 2.0, but it is between 0.5 and 1.5 for $S/M = 0.25$. It increases both with S and with F. It decreases with an increase in the age at which predation by seals begins, though it is insensitive to changes in the age at recruitment. It is also higher when seals start preying on fish younger than the age of recruitment to the fishery than it is when seal predation and the fishery commence at the same age. A value for R of 1.0 will be used for demersal fish in subsequent calculations, but an error of about ± 30% seems possible.

Factors Modifying the Impact

Methods of estimating the amount of commercial fish eaten by seals and the effect that this consumption will have on catches have been developed above. There are a number of points which could modify the simple approach used so far, and which would lead to changes in the estimates if more detailed analysis based on more comprehensive data were possible.

Local Distribution of Stocks

Nearly all the preceding comparisons are based on estimates of stock, catch and consumption over large regions. In smaller areas where seals are concentrated, the fish they take may constitute a much larger proportion of the stock and, possibly, of commercial catches. This could occur in the vicinity of seal rookeries, or perhaps where seals are concentrated to feed on an abundant food supply, for example in estuaries where salmon are running. Such effects are likely to be of more importance in the case of resident seal species, such as harbour and grey seals and sea lions, than for the more migratory species, like harp and northern fur seals. There appears, however, to be little or no evidence concerning the significance of such local effects. If the areas of high seal concentration are also areas of above-average importance to the fishermen – which is quite possible – then the overall impact of seals on the fisheries will be increased. On the other hand, it is also possible that fishermen and seals may hunt in different areas, and in this case the impact will be reduced. The importance of the impact will also depend to a large extent on the degree of mixing which takes place in the fish stocks. If the stocks consisted of a series of small, more or less discrete populations, the local effects would be much more important than if there was a large degree of mixing among the fish.

Migratory fish stocks may also be exposed to predation by seals to different degrees during different stages of their movement cycle.

Destruction Additional to Consumption

Seals may sometimes kill fish in addition to those they consume, or, in the case of larger fish, take a bite from them without eating them fully. The ICES (1981) ad hoc working group noted that "grey seals are believed to kill more fish than they eat". This seems to occur most conspicuously when seals take fish from fishing gear, such as salmon gill nets; the question is also discussed in Chapter 25. If the seals eat only part of the fish they kill, the estimates of consumption will be underestimates of the total numbers killed, and therefore of the effect on the stock. The Commissioners believe that this effect is small compared to other uncertainties in the estimates.

Selection of Prey

In the simple equations fish eaten by seals are treated as similar in all other respects, to the rest of the fish population. In particular, they are

assumed, if not eaten by seals, to be just as likely to be caught as any other fish. The effects of differences between the fishery and seal predation in the age distribution of the fish they take or in the geographical area of their operations have already been discussed. There could, however, be other differences between the fish taken by seals and either the population as a whole or the commercial catch. In particular, fish eaten by seals might be sick or otherwise abnormal animals which, if not so eaten, would die soon from other causes, and would therefore in any case, be unlikely to be caught. There is no direct evidence on this matter (see IUCN, 1982). The effect certainly exists with some large land predators, particularly those that run down their prey, so that the impact of, say, wolves on a deer population is much less than would be expected on the simple hypothesis. Where the size of the predator is similar to, or smaller than, that of the prey, as with wolves and deer, it certainly would be sensible of the predator to pick out the weaker individuals among the target population. For most seals, however, the weight of the prey may be one or two orders of magnitude less, and thus the incentive to pick out sickly individuals might be small. There are exceptions: an adult salmon is not so small compared to a harbour seal, or even a grey seal, and these animals seem adept at finding salmon at a disadvantage as when they are caught in a gill net or trap. (See Chapter 25.) In general, though, there is no evidence that seals eat a significant proportion of sick or vulnerable animals, and the Commissioners believe that any such tendency is not so widespread as to invalidate the preceding conclusions about the proportion of the fish eaten by seals which would, if not so eaten, be caught by fishermen.

Second-Order Effects

Another aspect that should be considered concerns the less direct, or second-order, effects on commercial fisheries from the consumption by seals of fish other than commercial species. These effects can, in principle, be significant or negligible, and can be positive or negative. In general it can be expected that increased predation by seals on a fish species which is not itself the target of commercial fishing will be beneficial to commercial fisheries if the prey species is a predator on, or a competitor with, commercial species, but will be harmful if the prey of the seals is also a significant food source for commercial fish. This statement is complicated by the fact that fish will change their trophic position as they grow from larvae to big fish, but it may be used as a guide to the second-order effects.

A possible example of a positive effect may be provided by the grey seal off Scotland. In some areas a major element in its diet is ling (SMRU,

1985), which itself is of minor commercial value, but is a significant predator on other species, including more valuable commercial species such as haddock and whiting. Thus increased consumption by seals could mean fewer ling, but more haddock and whiting. This may be so, although if it is, it might be argued that the best decision, in terms of fishery management, would be to encourage greater fishing effort for ling, and thus benefit directly from increased catches of ling, as well as from increased catches of other species.

Species of fish which are eaten both by seals and by commercially important fish may or may not themselves be exploited commercially. The non-commercial species eaten by seals appear to be mainly small fish and invertebrates, many of which are also food for cod and other commercial species. It is clearly impossible to put any reliable numbers on these second-order effects, but it seems reasonable to suppose that they will generally tend to increase the negative impact of seals as estimated from the direct effects.

Second-order effects involving commercially important species at two different levels of the food chain may also be important, but they will be even more difficult to assess. Seal predation will tend to reduce the availability of both prey species to the fishery, but if the result of a reduction in seals were to be an increased catch of the lower-level species, there might be no benefit at the higher level. The ultimate impact would depend on how the fisheries for the two species responded to the changed conditions and, to an important extent, on the relative values of the two species of fish. In general, there is probably a tendency for the higher-level, larger species of fish to be more valuable than the lower-level species.

The second-order effect of this kind which seems particularly likely to be significant is that arising from the predation of cod on capelin, which are the most important forage fish in the Newfoundland area. Figures quoted in an earlier section give estimates of total capelin mortality due to predation of several million t as compared with a maximum commercial catch of about 300,000 t. Cod account for a large proportion, perhaps two-thirds, of this predation. A change in the amount of capelin consumed by seals would probably lead to some degree of compensatory change in the amount consumed by cod. It is impossible to assess how effectively cod would be able to adjust to a change in the amount of capelin available. If the capelin decreased, the cod might be able to make up the deficiency from other kinds of prey; if the capelin increased, the cod might not be able to increase their rate of food consumption accordingly, or they might compensate by eating less of other species. The fact remains, however, that any

capelin no longer eaten by seals must ultimately be accounted for by some other source of mortality. Kohler (1964) found, in experiments, that cod fed on herring converted their food into body weight with an efficiency of about 25%, allowing for maintenance. This suggests that if, as an example, half of the capelin no longer eaten by seals were eaten by cod, the additional weight of cod produced might be about one-eighth of the weight of capelin not consumed by seals. Some proportion of this additional production of cod would be taken by the fishery. If this proportion was similar to the proportion which the fishery takes of the additional fish made available by reduction in seal predation (i.e., equal to R), the benefit to be gained by the fishing industry through this channel would seem not insignificant compared to that obtained directly through the fishing for capelin.

Another example of these second-order effects is provided by the sand lance, which is an important part of the food of grey seals near Sable Island and is also eaten extensively by larger commercial fish. Leim and Scott (1966) state that over half of the food of haddock in this area consists of sand lance.

Compensatory Effects

A final point that might reduce the expected impact of seals on fish stocks arises from possible density-dependent or similar effects in the prey population that might occur as a result of changes in seal consumption (e.g., compensating changes in the mortality rates from other causes, changes in recruitment, or growth). Similar effects have been suggested in order to modify the estimated impacts of heavy fishing, and these effects have been examined by many of those studying the dynamics of fish stocks, from the major study of Beverton and Holt (1957) onwards. These investigators have concluded that taking account of density-dependent effects on growth or natural mortality will slightly reduce the estimated extent of the effects of changes in the amount of fishing from the estimates obtained from simple models. Taking account of density-dependent recruitment effects will increase the magnitude of the estimated effects. Similar arguments can be applied to predictions of the impact of seal predation; that is, taking account of compensatory effects on growth and mortality (other than that due to seals or humans) will reduce the extent of any impact, while density-dependent recruitment will increase the estimated impact of seals on fish catches.

In any case, if, following a change in seal predation, fishing effort is modified in an attempt to maintain the fish stock at about the same target level, these density-dependent effects will be very small.

Other Impacts on Fish Stocks

So far the discussion has focused on the changes in fish stocks and catches from them, as a result of changes in the number of seals, on the assumption that other things were equal. Other things are not equal, however, and fish stocks off Canada have undergone changes as a result of fishing pressure or of natural factors other than seals that exceed any changes likely to be caused by changes in seal numbers. Similar changes may well occur in the future.

Environmental factors can cause great year-to-year changes in the numbers of young fish reaching a fishable size, the result, it is believed, of events during the first few weeks or months of life (Hjort, 1914; Cushing, 1973). These factors have been important in determining the variations in, for example, some capelin stocks (see above). Short-term changes of this kind could have the effect of masking changes in the level of catch caused by variation in the abundance of seals. These effects have been discussed earlier, particularly in relation to effects on Atlantic cod. Longer-term changes, of decades or more, can also be significant, and may sometimes be related to observable changes in climate. Thus the rise and fall of the cod stocks off west Greenland in the 1920s can be clearly associated with the warming of the water and the more recent cooling (Cushing, 1982). This temperature change may also have affected the distribution, and perhaps the abundance, of hooded seals. (See Chapter 21.)

The dominant impact on Canadian fish stocks during the past half-century has been human exploitation. By 1975, the stocks of many of the more valuable fish on both coasts had been seriously reduced from their pristine abundance by large catches made by Canadian and, especially in the Atlantic, by foreign fishermen. Since the 1930s, Canada, in association with other countries concerned, has taken part in a number of international agreements aimed at controlling the situation. These argreements include the International Commission for the Northwest Atlantic Fisheries (ICNAF) for all fisheries on the Atlantic, and a number of more specialized agreements on the Pacific, including bilateral agreements with the United States over halibut and over salmon originating in the Fraser River. These arrangements have achieved some successes in managing the stocks, although the sucesses have been far from complete, especially on the east coast. There, the need to reach agreement among a large number of countries with diverse economic interests often meant that the measures adopted were too weak and were applied too late.

Canada only acquired the ability to apply fully effective measures with the extension of its jurisdiction over fisheries in 1977. Since then considerable progress has been made in rehabilitating some of the most seriously depleted stocks, including many of the Atlantic cod stocks, but many stocks are still below their most productive, or most economically rewarding, levels. In biological terms, the impact of fishing on many stocks is too high, and in economic terms the capacity of the fishing industry, both afloat and ashore, is too large. A complete solution of these problems would involve large social and economic disruptions, at least in the short term, and thus is far from easy. The problems of the fishing industry on both coasts have been examined by a number of other inquiries (Canada, Task Force, 1983; Canada, Commission on Pacific Fisheries, 1982), whose reports provide full details and reference to the relevant literature.

Some spokesmen for groups opposed to sealing, while not denying that seals eat fish, have stressed that seals should not be the scapegoats for the depletion of fish stocks caused by excess human exploitation (Holt and Lavigne, 1982). It is undoubtedly true that in most recent years, fishermen would have benefited more from successful measures to control and reverse the effect of overfishing than from controlling seals. This does not alter the conclusion, however, that control of seals could bring benefits, and that these benefits would become relatively more significant as the efforts to manage the fishery became more successful.

These considerations do not influence the quantitative estimates of the effects of seals on fish stocks and fish catches. The estimates developed in this Report apply mostly to current conditions of fish stock abundance and fishing mortality, and if these do not change, and if environmental factors affecting year-class strength also stay the same, the validity of the estimates will not change either. If there are changes, the adjustments will generally be minor. For example, if climatic factors cause a decline in the fish stocks, then both catches and consumption by seals are likely to decline. The impact of seals on catches, in terms of tonnes of fish, will also decline, but will remain much the same as a percentage of the catch, except to the extent that either seals or fishermen change their predation rates, for example, by switching attention to relatively more abundant species.

Discussion

To this point discussion has been concerned with the feeding of seals and their relation to fish stocks in a somewhat descriptive manner. It now

turns to address more directly the basic question within the mandate of the Royal Commission: Is there any reason to consider controlling the abundance of seals because of their competition with fishermen for fish? This question can be addressed in three stages.

- Is there any impact of seal predation, that is, do seals affect the size of fish stocks, and through them the size of fishermen's catches?
- How large, in terms of weight and value, is the reduction in catch caused by the seals?
- How much would this impact change as a result of a change in seal abundance?

Is There an Impact?

The Commissioners believe that there can be no serious doubt that seals have an impact on fish stocks. Most of the evidence presented and submissions made to the Royal Commission on this subject accepted this point, though there were considerable differences about the magnitude and the social and economic implications of the impact. The report of a working party set up by the International Union for the Conservation of Nature and Natural Resources (IUCN), with support from the People's Trust for Endangered Species, and the International Fund for Animal Welfare concluded:

> *The first [question] is whether the concern of the IUCN and other bodies about the seriousness of the conflict, actual and potential [impact of fisheries on marine mammals as well as vice versa], between marine mammals and fisheries is justified. By and large, the answer is yes, despite the frequent lack of conclusive evidence (IUCN, 1982).*

In the first place, there can be no doubt that seals feed mainly on fish, and that a substantial, though variable, amount of that food consists of fish species that are taken by the commercial fisheries.

Secondly, we have been able, in this chapter, to consider estimates of the total quantities of food eaten by the principal seal populations. These estimates have been based on scientific evidence drawn from a variety of sources. While there are a number of points still subject to debate in the

underlying data, these uncertainties are relatively small. When they are taken into account, the Commissioners believe that the estimates of total food consumption for most of the major seal herds are likely to be correct within the range ± 40%.

The estimates of the amounts of particular fish species consumed are considerably less accurate than those of total consumption, because of the small size of the samples and the substantial seasonal and geographical variability. If, however, the consumption by one species is underestimated, that of another species must be overestimated by a similar amount in order to maintain the more precisely known total consumption.

Consequently, the estimates of amounts consumed of groups of similar species, taken together, are likely to be considerably more reliable than estimates for individual species. In our analysis we have therefore grouped together species, such as the commercially exploited demersal fish, which are harvested in a similar manner and to a similar extent by the fishery.

Although the effect of seal predation on commercial fish stocks and catches is difficult to demonstrate directly, many of the estimates of fish consumption by seals are of the same orders of magnitude as the takes of related commercial fisheries; and the ability of commercial fisheries to reduce the size of fish stocks to their own ultimate disadvantage has been only too widely demonstrated. It would seem to follow that the effects on the fish stocks would be similar whether a given quantity of fish is removed by fishermen or by seals, although seals, being opportunistic feeders, may have less tendency than the fisheries to push preferred species to low levels of abundance.

Nevertheless, although the evidence that seals can have an effect on the abundance of fish stocks and the size of catches seems overwhelming, the Royal Commissioners are not aware of any instance in which a known and measured change in the abundance of seals has had a measurable effect on fish catches. In this connection Dr. S.J. Holt stated in his brief (Holt, 1985):

> *It can be said that it emerges that there is no single case in the world where scientific evidence, dispassionately evaluated, supports the view that commercial fish catches will increase if seals are "controlled" by "culling".*

If this statement is interpreted to mean that no clear-cut cause-and-effect relationship between seal numbers and fisheries' catches has been demonstrated, it is largely true. Almost the only clear demonstration in the scientific literature of the effect of a change in the abundance of any marine mammal on a fishery concerns the impact of sea otters on abalone (Johnson, 1982; Wild and Ames, 1974). Here the circumstances for demonstrating the impact were exceptionally favourable; sea otters have abalone as one of their favourite foods, they are capable of imposing a serious impact, and there was a substantial increase in sea otter populations as they recovered from near extinction as a result of severe overexploitation in the 19th century.

In other cases where fishermen or others have expressed concern about the impact on their catches of increasing numbers of seals or other marine mammals, it has not been possible to make a clear scientific demonstration of a neat one-to-one relation between a change in marine mammal numbers and a change in fish stocks or fish catches. There are good reasons for this: the data base for both seals and fish is often poor; the expected extent of the impact is uncertain; and the change may be small relative to the other sources of variation in the system.

Northridge (1986) used his simulation model to examine the last point, and to test whether quite large changes in the rate of seal predation on cod would produce changes in the catch that would be noticeable when allowance was made for random variation in year-class strength from year to year. He used parameter values based on what is known of cod in the Labrador area, biomass and catch values similar to those discussed above, and a seal consumption of about 150,000 t. The results suggest that increasing seal predation by a factor of about 3 (from $S = 0.06$ to $S = 0.2$) would produce a decrease in the catch of about 29%, which seems to be about half the amount of the increase in the hypothetical consumption by seals (Northridge, 1986, Figures 14(a), 14 (b)). Northridge suggests that this change in the catch would be detectable by statistical tests in about 10 years, but such a detection could, in practice, still fall short of a convincing scientific demonstration, since other factors influencing the situation, such as climatic changes or modifications to fishing pattern, could well have occurred.

In another simulation using the same cod stock parameters (Northridge, 1986, Figures 13(a), 13 (b)), a halving of the seal consumption caused an increase in catch of 9%, and it does not appear that the change would be detectable by statistical analysis over the 50 years during which the changed conditions were run in the simulation.

In summary, there are many factors that can complicate the simple theory that the fewer fish that seals eat, the more there will be for fishermen to catch, but none of those considered here seem sufficient, either alone or in combination, to modify the conclusion that seals do have some impact on several Canadian fisheries. Further, nothing the Royal Commission has heard or read suggests that there are any serious doubts within the scientific community that such impacts do exist. The doubts that exist concern the question of how big, or how small, the impacts are in any particular case. This question is addressed next.

How Large Is the Impact?

The preceding sections have discussed the difficulties in estimating the extent of the impact, and it is clear that any figures obtained will be at best very approximate. At the same time, the degree of uncertainty should not be exaggerated. The estimates of total food consumption by the major herds are probably correct to within about ± 40%. The percentage that any given fish species makes up of the total diet of the seals is subject to major uncertainty, but the sum of the consumptions of the individual species must be equal to the total consumption which is relatively better known. By grouping together species with a similar position in the fishery, it may be possible, therefore, to reduce this uncertainty to a level which makes the resulting estimates of some practical value; they may show, for example, whether the impact is likely to be serious enough to merit further consideration.

Thus, if the loss to fishermen caused by seal predation can be expressed, even very approximately, as so many dollars per tonne of the main categories of food consumed by the seals, many of the problems which arise from trying to calculate losses for the commercially important fish species individually can be avoided. The following sections attempt to develop this approach for the Atlantic region.

The first step is to estimate the amounts of each of the main types of fish which are consummed by the seals. In a previous section it has been pointed out that the Canadian industry takes only a very small amount of fish in the waters inhabited by hooded and harp seals in summer in Davis Strait and off Greenland and the northeastern Canadian archipelago. These waters constitute Areas A and B in Figure 24.1 and they will be ignored in calculating the approximate impact of seals on the Atlantic coast fishery.

We have also discussed the likely amounts of the principal groups of commercial fish taken by each species of seal in the rest of the Canadian waters on this coast (Areas C to F). Table 24.13 summarizes the estimated total consumption by each species of seal in Areas C to F and the amounts which are believed to be composed of each group of fish species. The estimates for capelin, herring and demersal fish have been discussed in detail earlier. Grey seals probably eat some salmon, but the amount is likely to be small, and no estimate can be inserted in the table. Harp seals are believed to eat substantial amounts of shrimp, but much of this is probably taken in Areas A and B; there are no data on which to base any estimate of the amount of shrimp consumed in the other areas, but it is probably less than the amount of capelin taken. It was also noted earlier that only harp and harbour seals feed significantly on other pelagic fish; no good estimate of the proportion is available, but it is assumed here to be fairly small. (See Tables 24.1 and 24.3.)

The next step is to ascribe a financial value to the loss caused by the consumption of commercial fish as determined in the preceding paragraph. This process has two components: assessing the reduction in catch caused by the seal consumption and placing a monetary value on that reduction.

The problem of determining the value of the ratios (R) of the change in catch to the amount consumed by seals was discussed in a previous section. The values which were estimated for the principal species groups were:

capelin	0.1
herring	0.7
demersal	1.0

The effect of using other values for the population parameters, including the relative ages of first capture by seals and by the fishery, and the intensity of seal predation, has been examined earlier for several species. The results suggest that other combinations of likely values for the parameters commonly produce estimates of R within a range of $\pm$ 30% of the central value used, and this range will be used in the next stage of the calculations.

By multiplying these values of R by typical prices for the various fish classes, a "value factor" for each class is obtained which can be used to convert amounts consumed to losses to the industry. This is done in the following table, in which the average prices are rounded from values derived from the official statistics for 1981 and 1982 (Canada, DFO, 1984a). The value factor represents the loss to the catching side of the industry for each tonne of the various types of fish consumed by seals.

Table 24.13
Indicative Calculations of Loss in Catch to Canadian East Coast Fisheries as a Result of Seal Predation

		Harp Seal	Hooded Seal	Harbour Seal	Grey Seal
Total Consumption (1000 t)		3,500	1,500	17	240
Consumption in Areas C–F (1000 t)		1,300	500	17	240
Consumption of Commercial Species (1000 t)					
Capelin		30–130	–	–	–
Herring		1–3	–	2–3	43–65 (18–27%)
Demersal		90–155 (7–12%)	350–450 (70–90%)	5 (30%)	100–150 (42–63%)
Salmon		–	–	–	?
Shrimp		?	–	–	–
Other Pelagic		?	–	1–3 (5–20%)	–
Total		121–288	350–450	8–11	143–215
Value ($1,000,000)	Value Factor ($/t)				
Capelin	14–26	0.4–3.4	–	–	–
Herring	125–225	0.1–0.7	–	0.3–0.7	5–15
Demersal	250–460	22.5–71	87–207	1.2–2.3	25–69
Salmon	?	–	–	–	?
Shrimp	?	?	–	–	–
Other Pelagic	125–225	?	–	0.1–0.7	–
Total Value		23–75	87–207	1.6–3.7	30–84

	Capelin	Other Pelagic	Demersal	Atlantic Herring	Atlantic Salmon
R	0.07–0.13	0.5–0.9	0.7–1.3	0.5–0.9	0.7–1.3
Price ($/t)	200	250	350	250	6,000
Value Factor ($/t)	14–26	125–225	250–460	125–225	4,200–7,800

These values are subject to uncertainties of different kinds. The uncertainties in the values of R have been discussed above. The prices used can only be indicative, since the true prices vary with time and with the species and sizes of fish within the broad categories of other pelagic and demersal fish.

The results of these calculations for the Canadian Atlantic fisheries are set out in Table 24.13. This table does not include provision for any impact on the fishery from seal predation on Atlantic salmon, shrimp or sand lance, since the data available for these species are inadequate. Grey seals, and possibly harbour seals, are known to eat some Atlantic salmon. The large size and very high value (about 15 times that of cod) of these fish must make any impact of seal predation relatively large in proportion to the number of fish taken, but there are no data on which to base even an approximate estimate of the number consumed. Crustaceans, including a proportion of shrimp, are eaten quite extensively by harp seals in both their summer and their winter feeding grounds, but it is not possible to relate the amounts consumed to individual species, still less to stock size or catch levels. As was shown above, attempts to do so only reveal apparent discrepancies in the data. Sand lance are reputed to be an important food for grey seals around Sable Island, but there are no data on which to develop an estimate of the amount consumed. There is currently no significant fishery for sand lance in the western Atlantic.

The ranges given in Table 24.13 for the estimates of loss are based on the ranges of values adopted for the value of R for each category of fish, and for the percentage of each category of fish in the diet of each species of seal. It should be realized that the lowest estimates of the loss due to any species of seal would be correct only if the correct values of R for all fish categories were those given at the lower end of the range, and if the correct values of all the percentages of the diet for all fish categories were also equal to the lower end of the range. Similarly, the highest estimate of total loss would be correct only if the true values of all Rs and all percentages in the diet were those given as the high end of the range. If some true values are nearer the

upper end of the ranges and others nearer the lower end, then the true losses would be at some intermediate point in the range given. If some of the true values of R or of percentages in diet are outside the ranges used in the table, the losses could be above or below the range given, but this would occur only if, for example, some value or values were below the range, and all the others were at or near the bottom end.

The estimates of loss given in Table 24.13 are based on the assumption that the single values used for the total consumption by each seal population are all correct. In an earlier section it was suggested that these estimates might be subject to a probable error of ± 40%. These error ranges could therefore be superimposed on the estimated losses attributable to each species of seal. It must be emphasized again that these extreme values would be applicable only if, in the lower case, the true values of all the Rs and all the percentages in the diet were at the bottom end of the ranges given, and the total consumption estimates were 40% too high; or, in the upper case, all true values were at the top of the ranges and the total consumption estimates were all 40% too low. Readers will exercise their own judgment as to whether such combinations of errors are likely.

The estimates of loss due to each species of seal listed in Table 24.13 have not been combined to provide an estimate of the total loss attributable to all species of seals on the Atlantic coast. There are two reasons for this. First, for the purpose of practical applications, it will be necessary to consider each species of seal separately in determining the appropriate management policy. Secondly, there are great differences among the species in relation to the nature of the principal uncertainties which affect the values of the estimates, and these differences, combined with the great differences among species in the size of the estimated losses, will tend to make any process of combination rather meaningless.

Probably the greatest problems in assessing the accuracy of these estimates apply to the hooded and harp seals. The greatest uncertainty with the hooded seal lies in the extent to which it preys on fish stocks which are subject to exploitation by the Canadian fishery. In Table 24.13 it has been assumed that two-thirds of the food of the northwest Atlantic hooded seal stock are taken in Areas A and B, where these seals do not compete with the Canadian fishery; it has been further assumed that the 70%–90% of the diet in Areas C to F, which consist of demersal fish, is taken from stocks which are exploited by Canadians. Very little is known of the location of the main feeding areas of hooded seals in Areas C to F, and, in particular, of their relation to the principal fishing grounds. It is not impossible, therefore, that there is less overlap, and therefore less impact, than has been assumed in

the table. Furthermore, the figure for the proportion of commercial demersal fish in the diet is based on Greenland data, and no useful data are yet available for Canadian waters. There is little room for the true figure to be higher than the value of 70%–90% which has been used, but a lower figure is not impossible. There seems no doubt, however, that the hooded seal does feed predominantly on medium to large demersal fish, and that a substantial proportion of these fish are likely to be commercially important. The implications of the data in Tables 24.10, 24.11 and 24.13 are that in the absence of hooded seals, demersal catches in Area C would approximately double. This is dependent, however, on the assumptions that about one-third of the food of hooded seals is taken in Area C and that most of the demersal fish component taken there is from stocks subject to Canadian fisheries. These assumptions may well be true, but the resulting very large estimate of the impact should be regarded with reservation until much more data are available.

The difficulty with the harp seal arises principally from the fact that the estimated total food consumption is so great that even small errors in the proportion of its food taken from commercially important stocks can produce quite large changes in the absolute estimates of total impact. The uncertainty in the proportion of the food taken in areas of importance to Canadian fisheries is considerably less than that for the hooded seal; there is some uncertainty about the proportions of the total food taken in Areas A and B and in Areas C to F, but the relative values used (about 60%, 40%) are unlikely to be seriously in error. The greater uncertainty lies in the proportion of the food which is taken from commercially exploited stocks. In Table 24.13 the estimated consumption of commercial species by harp seals is 9%–22% of total consumption, and this does not include any allowance for the consumption of commercially important shrimp. On purely mathematical grounds therefore, it would be possible for the commercial fish consumption to be underestimated by a factor of 3 or 4. There seems no doubt that capelin is an important food of harp seals in this area, but just how important is not clear. The significance of errors relating to capelin will, however, be reduced by the relatively lower value of this fish, which leads to a lower monetary impact. The great fluctuations, both in the size of the capelin fishery and in the size of the stock, add a further element of uncertainty to the appropriate value of R for these stocks. Demersal fish, and possibly pelagic fish other than capelin, form only a small proportion of the diet of harp seals, but the very fact of the smallness of the proportion makes it extremely difficult to estimate. The values used in the calculations may, therefore, be subject to relatively wide probable errors. The high value factor for these species, combined with the large total consumption by harp seals, can cause relatively small uncertainties in diet percentages to produce

large uncertainties in the resulting estimate of the size of the impact. The relative stability of the demersal fish stocks and the operations of the fishery suggest that the value of R for these species is subject to less uncertainty than that for capelin. The same applies to pelagic commercial fish.

Grey and harbour seals feed almost entirely within the area of Canadian fishing operations; the uncertainties in the estimates of loss due to these species therefore arise mainly from the estimates of total food consumption, the proportions of the principal fish types in the diet, and the values of R. The ranges of estimates of loss given in Table 24.13 can therefore be viewed with more confidence than those given for harp and hooded seals.

No allowance has been needed in the estimates of loss for the fact that in some fisheries the catch is headed and/or gutted before landing; this is because the values per tonne used are adjusted to live (round) weight landed values. Use of prices prevailing at other levels in the marketing chain (e.g., wholesale, retail or export) would, of course, lead to higher estimates of the loss. No allowance has been made for elasticity in fish prices, but this seems to be appropriate. Fish prices are largely determined by the world market, and any variation in supply resulting from a change in the level of predation by seals might not have any significant effect.

Similar calculations could be made for the Pacific coast fisheries. They have not been attempted here for two reasons. One is that the data base is even more uncertain than that pertaining to the Atlantic coast. The other is that the impact on the fisheries is likely to be much less, since the estimated total food consumption is smaller by nearly two orders of magnitude.

Effect of Changing Seal Numbers

If consideration is to be given to reducing the numbers of seals in order to diminish the losses to the fishing industry, it is necessary to have some basis for assessing what effect a given change in numbers of seals will have on the amount of the losses. A number of factors are involved in this question.

- The total amount of food consumed will be proportional to the number of seals unless individual food consumption changes as the population size alters.

- The composition of the food may change with the number of seals.
- The ratio of loss of catch to seal consumption, *R*, may change with the amount consumed.

The question of changes in individual consumption in response to changes in population size is discussed briefly elsewhere in this chapter. Scientists do not fully agree about the direction in which such changes would operate, and it is likely that they would also be small compared to the direct effect of a change in the number of seals on overall consumption. Thus, total consumption will change in the same direction as changes in seal numbers, but perhaps not exactly in the same proportion.

It is possible that if the number of seals were reduced, they would be able to take a greater proportion of their food from preferred species. If these preferred species were also commercially important, the change in the impact on the fishery would be proportionately less than the change in the seal population. An opposite effect might occur if the number of seals increased, but such possibilities are only speculative at this stage.

The influence of a change in the seal population on the ratio of loss of catch to consumption can be examined by modelling techniques such as those in Northridge (1986) and Appendix 24.2. These or similar techniques could be used to examine any specific proposal. In general, it appears that the changes in the ratio are not likely to be great.

In the initial stages of developing policy relating to control of seal numbers for the benefit of the fishery, it seems reasonable to assume that the reduction in the loss attributable to seal predation on commercial fish would be roughly proportional to the reduction in the seal population.

Adjustments of Fishing Patterns

The foregoing discussions have dealt with one question: By how much will fish catches change, all other circumstances being equal, if the consumption by seals changes by a given amount? In particular, it was assumed that fishing mortality was held constant. Consideration should also be given to the degree to which changes in seal consumption might be followed by changes in fishing mortality.

The Royal Commission did not attempt to make a detailed review of Canadian fish stocks, although some information is given by Northridge (1986). It is clear, however, that the dominant factor in determining the abundance of the major commercial species on both coasts has been fishing. Further, some of these stocks (e.g., cod on the east coast, herring on both coasts) have been depleted in the past below their optimum level either by Canadian fishermen alone, or by the joint efforts of Canadian and foreign fishermen. This is true regardless of what precise definition of "optimum" is used.

This situation is now changing, especially since the introduction of the 200-mile limit. Canadian fisheries are, in principle, being managed, and the catches in most major commercial fisheries are subject to controls such as quotas. The basis of these controls varies from stock to stock; it includes objectives such as maintaining some target escapement (especially for salmon), exerting a fishing mortality equal to $F_{0.1}$ (mainly demersal stocks), or ensuring that the spawning stock does not fall below some prescribed level. In all cases, the nature and effectiveness of the controls depend on the biological situation, in which predation by seals must be a component.

If seal predation is reduced, it should be possible, at least in theory, to increase the fishing pressure while continuing to achieve the objectives for which the fishery is being managed. Since the fishery would now, in a sense, be replacing the predation previously exercised by the seals, the new regime should be able to provide a greater increase in yield than that indicated by the simple model in which fishing pressure is kept constant. If the seals and the fishery are taking fish of precisely the same range of ages, then the increase in catch should be exactly the same as the reduction in seal predation. Since, however, the age ranges are often very different, the increase in catch and the reduction in predation will not be the same. Modelling techniques such as those in Northridge (1986) could be used to examine possible effects in such cases.

Before any adjustment could be made to fishing pressure to maximize a gain in yield resulting from a reduction in seal predation, it would be necessary to have a much more detailed understanding of exactly what effects seal predation is producing than would be possible at present. Basically, two approaches are possible. The first is the continuation and extension of present studies of the population dynamics of commercial fish stocks with the aim of measuring any changes in population parameters, especially year-class sizes and mortality rates, which can be correlated with changes in seal abundance. The second is to undertake much more extensive and detailed studies of seal biology, particularly as it relates to seal distribution

and feeding, so as to place studies of the kind which have been outlined in this Report on a much sounder basis. The most critical questions are: Where and when do seals feed? What kinds of animals do they eat? What is the size and age composition of their food as compared with the population composition of the prey species? In addition, more needs to be known about the overall amounts of food that seals require, although present knowledge of this point, as it relates to most seals, is considerably better than knowledge of the composition of the food, and where and when it is taken. The problems involved are so complex, however, and the present level of knowledge so deficient that it will be necessary to undertake a major continuing research program for some time along all these lines before a sound basis for the joint management of seal and fish populations can be established.

Summary

1. The species of seal which may have significant impacts on commercial fish stocks are harp, hooded, harbour, grey and northern fur seals, and Steller and California sea lions. The northern elephant seal occurs in negligible numbers in Canadian waters, and the ranges of the ringed seal and bearded seal do not overlap substantially with commercial fisheries.

2. The food of all the seals making significant impact consists mainly of fish and sometimes of significant amounts of squid and shrimps. Seals are opportunistic feeders, and the composition of their food varies greatly, not only among species, but also with time and place. Because of this and because of the small amount of material which has been examined, even for relatively well-studied species like the harp seal and the northern fur seal, it is only possible to determine in very general terms what proportion of the food is made up of the various prey species.

3. All the species of seals listed above include a substantial amount of commercial fish or invertebrates in their food. The most important species are:

harp seal:	capelin, herring, shrimp
hooded seal:	deep-water demersal fish
harbour seal (east coast):	herring, flounder and other commercial demersal fish

harbour seal (west coast):	salmon, herring, possibly other commercial species
grey seal:	commercial demersal fish, possibly salmon
northern fur seal:	herring, squid, salmon
Steller sea lion:	herring, salmon, commercial fish generally
California sea lion:	herring.

4. Examination of information on the stomach contents and rate of digestion of seals, their food requirements in captivity and their energy requirements suggests an average food requirement for wild seals of about 6% of body weight per day for the smaller species, grading down to 4% for the largest. These figures are used in subsequent calculations. The actual requirement of an individual seal is, however, affected by its rate of growth, level of activity and reproductive condition, as well as the energy content of its food.

5. Combining the estimates of the sizes of the various seal populations with those of the food requirements of individual seals provides estimates of total food consumption which are given in Table 24.9. These estimates should be regarded as, at best, correct within ± 40%.

6. Harp and hooded seals consume much larger amounts of fish than any of the other species examined, but their impact on Canadian fisheries is not proportionally as great. Harp seals in summer and hooded seals during most of the year feed largely in Davis Strait and off Greenland and the northeastern Canadian archipelago, where little Canadian fishing takes place. Hooded seals, when further south, also feed in deep water which may to some extent be outside the range of the fishery. Harp seals are thought to feed largely on capelin, and to some extent on shrimp and small demersal and pelagic fish, but non-commercial species may form a substantial proportion of their diet. Hooded seals feed to a large extent on medium to large demersal fish, some of which are of commercial interest. In the following discussion consumption by hooded and harp seals in the northern regions (Areas A and B in Figure 24.1) is ignored.

7. It is possible to attempt any quantification of the impact by seals only for the following stocks:

Capelin. The best estimate of the present amount consumed by harp seals in the southern area is within a probable range of 30,000t –130,000 t, but considerably more may have been eaten in earlier years when capelin were more abundant. No other seals take significant amounts of capelin. Comparison with the stock size and catches is complicated by wide fluctuations in both, due to effects of heavy fishing and of environmental factors. Biomass has varied between 0.5 and over 4 million t. Catches since 1973 have ranged between 30,000 t and 350,000 t, and are currently somewhere about the lower end of this range.

Other major predators on capelin are birds, cetaceans and particularly cod; at a rough, but possibly low, estimate harp seals may account for about 1%–5% of the total predation. Calculations suggest that any change in seal consumption of capelin would produce a change of the order of one-fifth of that amount in the commercial catch in periods of moderately high fishing effort, assuming that recruitment to the capelin stock did not vary. If fishing intensity on capelin is low, as it is at present, the impact will be correspondingly less.

Atlantic herring. Harp seals feed on herring, particularly in the southern Gulf of St. Lawrence (Area 4T) in the spring. Estimates of the amount consumed in the 1970s, using different methods, and with reference to different periods, are 7,000 t and 21,000 t, but at the present low level of the herring stock, consumption seems likely to be currently much less. The recent TACs here have averaged about 16,000 t so that seal predation seems to take about the same order of magnitude as the catch.

Harbour seals appear to take about 2,000 t–2,900 t of herring off the Nova Scotia coast (Area 4WX). This amount is relatively small compared to an estimated biomass of 335,000 t and a recent catch of 81,000 t.

Application of the population model suggests that a change in seal consumption of Atlantic herring will produce a slightly smaller change in the catches.

Pacific herring. All species of seals on the Pacific coast consume herring; their estimated combined consumption is about 16,000 t–20,000 t. This amount can be compared with a recent biomass of about 900,000 t and an average catch of 50,000 t. Thus consumption by seals is of the order of half the present catch. The model indicates that a

change in consumption would change the catch by only about one-fifth of the amount involved, but if the present policy of regulating the fishery to try to maintain a constant spawning stock could be successfully maintained, this ratio would move up towards 1.0.

Shrimp. Crustaceans, including shrimp, are eaten quite extensively by harp seals, particularly in the north, but it is not possible to give useful estimates of the amount consumed. Some estimates suggest that consumption could be large compared with stock size and catches.

Salmon. Atlantic salmon are eaten to some extent by grey seals, but it is not possible to assess the effect on the stock or on the catch.

Pacific salmon of all species are eaten by harbour seals, northern fur seals and Steller sea lions. The amount consumed is likely to be in the range 10,000 t–11,000 t. This amount may be compared with a recent average commercial catch of 64,000 t. Since there is often direct competition between the seals and the fishery as the fish return to spawn, a reduction in seal consumption might lead to an equivalent increase in catch if effort in this closely regulated fishery could be adjusted to keep escapement at about a constant level.

Demersal fish. These bottom-living fish, which are the target of trawl and some line and net fisheries, are best considered as a group. On the Atlantic coast they are an important component in the diets of hooded and grey seals, and are eaten to a lesser extent by harbour and, possibly, harp seals. On the Pacific coast they are relatively minor components of the food of harbour seals and sea lions. The total amounts consumed are estimated to be: Atlantic coast, 540,000 t–760,000 t; Pacific coast, 18,000 t–23,000 t. On both coasts these amounts are fairly similar to the commercial catches of these species. The reduction in commercial catch caused by seal predation on demersal fish is calculated to be about equal to the amount taken by seals.

Squid. Squid are eaten frequently by harbour seals on the east coast and by northern fur seals on the west coast, but it is not possible to evaluate the importance of this predation.

8. Very approximate calculations indicate that the reduction in the landed value of the Canadian Atlantic fisheries because of predation by the existing seal herds is very large and probably significant when compared with the value of recent Canadian commercial catches in

the area. The loss on the Pacific coast is very much smaller, perhaps by as much as two orders of magnitude, and also, very much less than the value of the catch. These figures are subject to a number of constraints which have been discussed in this chapter. Moreover, they do not allow for indirect effects which would arise if seals are eating significant amounts of species which are prey of, or predators on, commercial species. As an example, it is possible that the benefit to be gained by the fishing industry from increased production of cod as a result of reduced predation by seals on capelin could be significant. It is also possible, if less likely, that there are indirect effects in the opposite direction due to seals feeding on carnivorous fish like hake which also prey on commercially valuable species.

Conclusions

1. Seals consume large quantities of commercial fish in Canadian waters and, consequently, cause a reduction in the catches of fishermen. On the Atlantic coast, roughly five million tonnes of a wide variety of fish and some crustaceans and molluscs are consumed, mainly by harp and hooded seals. Rather less than half of this amount is taken on or near commercial fishing grounds off southern Labrador, Newfoundland, the Maritimes and Quebec. On the Pacific coast, only about 90,000 tonnes are consumed. Although some of this, on both coasts, consists of non-commercial species, the consumption of commercial species is considerable. This must have some impact on catches, though the catch will not be reduced by exactly the amount of the consumption of that species by seals. For some lightly exploited stocks the reductions, if any, may be much less than the seal consumption, but for heavily exploited species the reduction may be similar to or exceed the amount consumed.

2. The value of the difference between the actual catch and that which could hypothetically be taken in the absence of predation by seals can be estimated only approximately, primarily due to a serious lack of information regarding the nature and amount of food taken by seals. There is, however, also a need for much greater understanding of the inter-specific and density-dependent effects in the marine ecosystem.

3. On the Atlantic coast the value of this unavailable catch is undoubtedly very great; it is clearly significant in comparison with the total value of the current commercial catch. Less information is available regarding the potential losses on the Pacific coast, but they appear to be very much smaller, not only in absolute terms but also in comparison with the commercial catch.

Appendices

Appendix 24.1. Calculation of Relation between Change in Catch and Change in Seal Predation in a Simple Model

Given a fish stock (N) subject to constant instantaneous rates of natural mortality (excluding seal predation), fishing mortality and seal predation of M, F and S respectively, then by the time the entire stock is dead and if $F/M = a$ and $S/M = b$:

$$\text{Catch} = C = NF/(M + aM + bM) = aN/(1 + a + b)$$

$$\text{Seal consumption} = H = NS\,(M + aM + bM) = bN/(1 + a + b)\,.$$

If the seal predation rate is changed by a factor k:

$$\text{Catch} = C' = NF/(M + aM + bkM) = aN/(1 + a + bk)$$

$$\text{Seal consumption} = H' = NS/(M + aM + bkM) = bkN/(1 + a + bk)\,.$$

The ratio of change of catch ($C' - C$) to change in seal consumption ($H - H'$) is then given by:

$$\mathrm{R} = \frac{C' - C}{H - H'} = \frac{a/(1 + a + bk) - a/(1 + a + b)}{b/(1 + a + b) - bk/(1 + a + bk)}$$

which simplifies to:

$$R = a/(1 + a) = (F/M)/(1 + F/M)\,.$$

Appendix 24.2. Calculation of Change in Yield per Recruit Following Elimination of Removal of Fish by Seals

Using the previous notation, we can write for year t to $t + 1$:

Seal removals $= H_t = N_t S_t W_t [1 - \exp(-M - F_t - S_t)]/(S_t + F_t + M)$,

Catch $= C_t = H_t F_t / S_t$.

Next year's initial stock $= N_{t+1} = N_t \exp(-M - F_t - S_t)$.

Total removals and catch are then given by:

$$H' = \sum_0^\infty H_t \quad \text{and} \quad C' = \sum_0^\infty C_t .$$

In the absence of a take by seals $S_t = 0$ for all t and the total catch is then C''. The ratio of the increase of yield to the amount previously taken by seals is then given by:

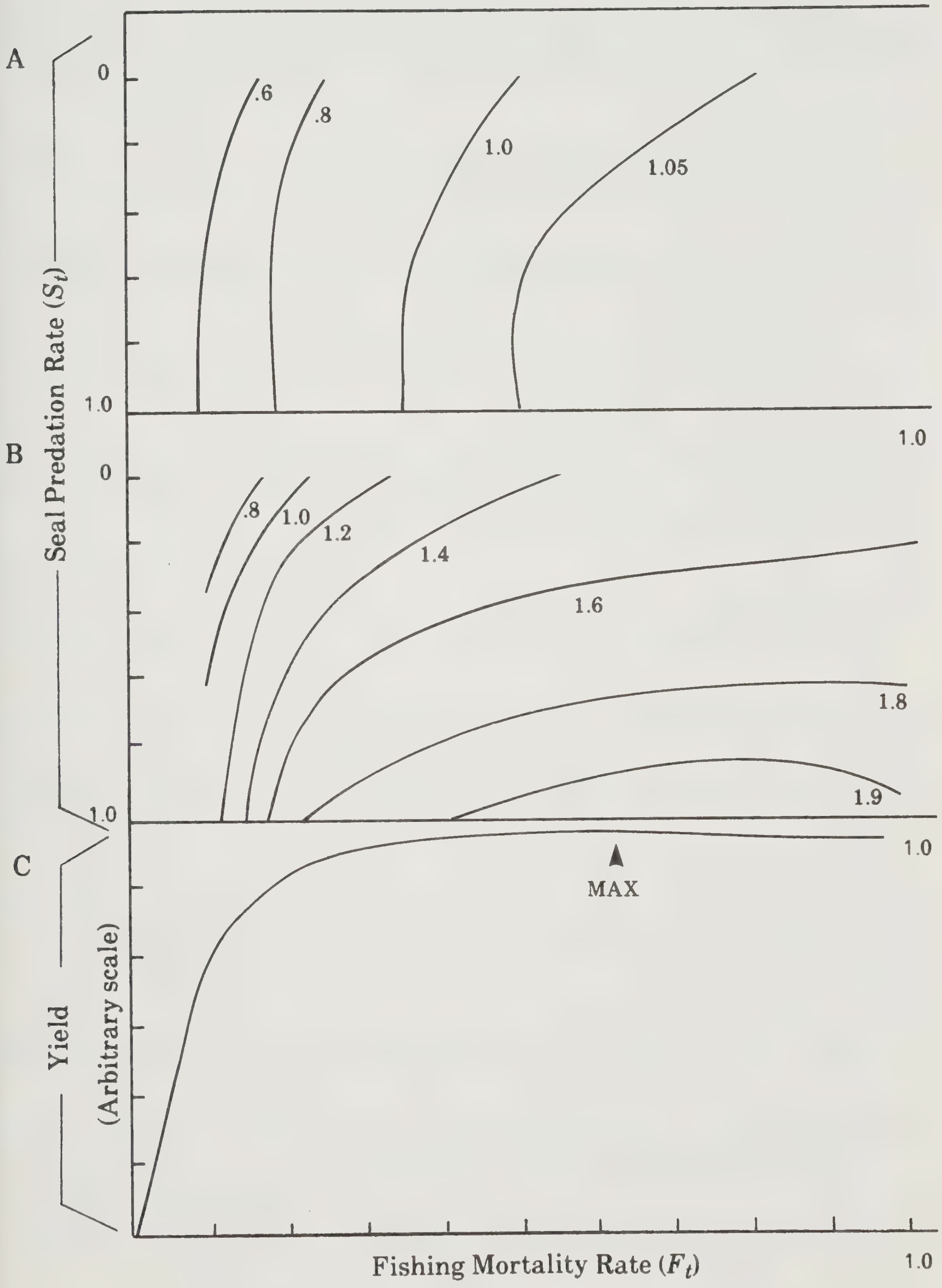
$$R = (C'' - C')/H' .$$

In applications where the initial ratio H'/C is known or assumed, S_t could be adjusted for a given series of F_t to produce the desired value. The application can be extended to determine the increase in catch produced by any defined reduction in the level of seal removals.

A computer program has been written to carry out these calculations with F_t and S_t set at constant values over defined ranges of fish age, and with W_t determined at the mid-point of each year, using the von Bertalanffy growth curve and isometric growth. To demonstrate the properties of the model it has been run for a range of values of S_t and F_t with $M = 0.2$: $K = 0.2$: $t = 0$: $W_\infty = 1$.

Figure 24.3 shows the isopleths for R for values of F_t and S_t between 0 and 1.0; for run A both fishing mortality and seal predation were taken as beginning at age 4; for run B fishing mortality began at age 4, but seal predation at age 2. Run C shows the value of the yield in the absence of seals for values of F_t between 0 and 1.0.

Figure 24.3
Yield Isopleths for R (A and B) and Yield in the Absence of Seals (C)



Appendix 24.3. Calculation of Change in Yield in a Gauntlet Fishery Following Elimination of Removal of Fish by Seals

Ignoring natural mortality and growth over the relatively short period involved, if the number of fish entering the fishery is N, then the catch (C), removal by seals (H), and escapement (E) are given by:

$$E = N \exp(-F - S)$$
$$H = NS[1 - \exp(-F - S)]/(F + S)$$
$$C = NF[1 - \exp(-F - S)]/(F + S)$$

where F and S are the instantaneous fishing and seal predation mortality rates, taking the duration of the fishery as unit time.

It follows that: $E = N \exp[-F(C + H)/C]$

From which $F = C \ln(N/E)/(C + H)$.

In the absence of seal removals, escapement (E') is given by:

$$E' = N \exp[-C \ln(N/E)/(C + H)]$$

which simplifies to:

$$E' = N^{H/(C + H)} E^{C/(C + H)}.$$

The new catch is given by $C' = N - E'$.

The proportion of seal consumption which has been added to the catch is then given by:

$$R = [E^{C/(C + H)} N^{H/(C + H)} - E]/H.$$

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Chapter 25

Damage to Fishing Operations

Since the 1970s the fishing industry has been reporting ever increasing interactions with grey seals resulting in damaged gear and partially consumed fish in their nets (Canada, DFO, 1985).

Introduction

Complaints by fishermen about seals taking fish from their nets and damaging them are commonplace wherever fishermen and seals come into contact. Overall the amount of damage may not be great, but it is clear that losses are concentrated in certain areas, and that some types of gear are much more vulnerable than others. Thus the effect on some fishermen can be considerable. A review of this problem in eastern Canada is provided by Mansfield and Beck (1977). Entanglement in fishing gear can also cause the death of the seal. This additional source of unnatural mortality and its possible impact on seal populations is considered in Chapter 23.

The losses to fishermen fall into several categories:

- fish that are damaged, or removed completely from the catch;
- removal of catch and bait from lobster and fish traps;
- physical damage to the gear;
- loss of fish from the gear because of this damage;
- time lost from fishing to repair the damage;
- catch lost because gear is not being used;
- time spent patrolling to keep seals away from nets and aquaculture pounds; and
- modifications to gear or fishing practice needed to reduce seal damage.

None of these losses are easy to quantify, though some estimates are presented on gear damage. However, unlike most matters concerning seals, there is little argument about the occurrence of damage. Arguments arise in the matter of whether, in the words of the official Greenpeace policy document on seals, it is true "from the limited information available that seals pose an insignificant threat to fisheries equipment" (Greenpeace International, 1985), whether damage is important only locally to individuals, or whether it is also significant on a broader regional basis. Furthermore, if damage is significant, there is the question of whether reducing the overall numbers of seals is the most appropriate method of dealing with the problem.

The most active types of Canadian gear (trawls, purse-seines and others) do not seem vulnerable to seal damage. Cape fur seals in South Africa, however, interfere greatly with the fishery by purse-seines and, to a lesser degree, with the trawl fishery. Moreover, seals on both coasts of Canada take fish from all types of hook and line gear. Set-lines may be the most vulnerable type of such gear because they may keep the fish available to the seals for some time. But fish caught with trolling lines and sports gear are also occasionally removed or damaged by seals though usually no damage to the gear or other associated losses are involved. The most vulnerable types of gear are the fixed gears, such as gill nets or fish traps, which allow the seals to approach or enter the gear in order to get fish. When the seals do so, they may become entangled and damage the gear in attempts to escape. The resulting holes may allow all or most of the fish inside fish traps and culture cages to escape. For fish farms and for some types of fish traps in which most of the season's catch may be taken in a few days, these losses can be severe. In eastern Canada the fisheries most affected are gill nets for herring, mackerel, pollock, cod and salmon; fish traps for herring, mackerel and salmon; and lobster pots (Mansfield and Beck, 1977).

Table 25.1 shows the value of the fisheries catch taken in each province (excluding arctic Canada) by the main types of gear, grouped according to their vulnerability to seal damage. It indicates the importance of traps in all the Atlantic provinces. Gill nets are important in Newfoundland, but elsewhere account for a relatively minor 5%–10% of the total value of the catch. The following sections provide a more detailed, province-by-province examination of the extent of damage and loss. It draws on a report for the Royal Commission on damage by seals to fishing gear in Canadian waters (Northridge, 1986).

Table 25.1
Value of Fish Landed in 1983, According to Type of Gear (in $ million)

Type of Gear	Newfoundland	Quebec	N.S.	N.B.	P.E.I.	B.C.
Stationary Gear						
Set gill nets	32.4	0.8	6.3	3.2	2.8	-
Drift gill nets	-	-	1.3	0.8	0.1	-
Other gill nets	-	6.0	-	-	-	20.8
Salmon nets	-	0.8	0.3	0.5	-	18.0
Weirs	-	0.5	0.1	2.0	-	-
Fish traps	17.3	-	-	-	-	-
Traps/Pots	22.4	17.8	73.8	51.7	28.5	9.9
Sub-total	72.0	25.9	81.8	58.2	31.4	48.7
Mobile Gear[a]	69.5	18.2	148.8	16.7	6.5	109.7
Hook and Line	25.3	1.3	42.2	1.0	1.1	34.3
Other Gear[b]	-	-	3.6	2.2	3.8	6.2
Total	166.9	45.4	276.4	78.1	42.9	198.9

Source: Northridge (1986).

a. Trawls, purse-seines, Danish seines, etc.
b. Rakes, harpoons, etc.

Nova Scotia

The stationary gears of Nova Scotia produce, in terms of value, the highest catch of any province, largely because of the high proportion of valuable lobsters. The waters of this province also contain the main concentrations of grey seals, and harbour seals are also numerous. The problem of seal damage has therefore attracted considerable attention, and the most detailed studies have been made in this province.

Questionnaires circulated to, or personal interviews conducted with, 96 fishermen over the eastern part of Nova Scotia in 1975, between Ship

Harbour, Halifax County, and Scatari, Cape Breton Island, indicated that an individual fisherman may suffer losses of gear to the value of $1,000 in a single year. The estimate of average losses of gear was $300 per fisherman or a total of $450,000 for the 1,500 fishermen of the area. These estimates did not include the losses of netted fish to the seals and the interruption of fishing while the gear was being mended or replaced (Mansfield and Beck, 1977).

Grey seals are very effective in robbing the nets of salmon fishermen, especially in areas near their summer concentrations. Seals also enter the traps set for mackerel and herring, mutilate large numbers of fish and sometimes drive the fish through the trap opening back to the sea. Salmon-trap fishermen at Guysborough, N.S. estimated losses of 30%–45% of their catch to seals. In areas where suitable haul-out sites for grey seals are close, trap complexes cannot be used. Seals open lobster traps or force their way into them and steal the bait, allowing the lobsters to escape and preventing further catches until the trap is baited and set again (Mansfield and Beck, 1977). In New England, fishermen report that harbour seals eat lobsters taken from traps (Anthony, 1985).

Zwanenburg and Beck (1981) reported on a survey of grey seal damage conducted during 1978; again this survey covered the fishery from Halifax County to Scatari, Cape Breton. The 105 licensed fishermen using stationary gear who completed questionnaires for the entire fishing season, stated that the average damage caused to gear by seals amounted to $105 per fisherman; an estimated maximum cost to all of the 1,500 fishermen of the area was $157,000. This figure represented maximum cost because some of the fishermen not surveyed were using mobile gear. These values are lower than those quoted above by Mansfield and Beck (1977). This same study also showed considerable variation in costs along the coast: the mean damage to fishermen in the 11 statistical districts for which data were reported ranged from zero to $308.

The Eastern Fishermen's Federation (EFF) made a study of gear damages by grey and harbour seals in Nova Scotian waters in 1983 (Farmer and Billard, 1985). The study was confined to damage by seals to fixed gear and included the costs of repair and replacement, when necessary, of the damaged gear. It did not include fish injured or lost from the gear to seals, loss or replacement of bait taken by seals from lobster traps, and fish or lobsters lost because the gear was too badly damaged to fish. The area investigated covered most of the outer Atlantic coast of Nova Scotia from northern Cape Breton to the beginning of Minas Channel in the Bay of Fundy, but excluding the Halifax area – a larger area than that covered by the previous studies. Random selections of fishermen using fixed gear were made for ar-

eas where damage was expected and for control areas where it was likely that damage would be less, because of the greater distance of those areas from seal aggregations. A sample population of 297 fishermen responded to the survey from a parent population of 3,380 fixed-gear fishermen. By averaging the total losses for the sample population (Table 25.2), the average yearly loss per fisherman is estimated at $236. When adjusted to the parent population by a factor of 11.38 (3380/297), the total yearly losses to gill nets, fish and lobster traps caused by seal damage in the area of Nova Scotia investigated are estimated at $799,000. The report did not provide a detailed description of the forms of damage, but a submission from the Lobster District 4B Working Group (1985) related that as many as 75–100 bait bags were removed from lobster traps in the vicinity of harbour seal colonies in one day's fishing, and that some fishermen had lost up to 1,500 bait bags in a season. In addition, seals broke into many heads of traps. Only the damage to gear, and not the loss of bait, is recorded in Table 25.2.

Farmer and Billard (1985) conducted a further econometric study of the data to produce better estimates of the losses. This analysis produced the following values for repair and replacement costs of gear damaged by seals and the labour involved in repairs for the 297 respondents:

Mackerel–herring gill nets	$ 71,558.15
Groundfish gill nets	$ 5,518.60
Wooden lobster traps	$ 13,764.24
Total	$ 90,840.99

(An error in their value for the groundfish gill nets has been corrected.) The authors did not include the fish trap losses in the analysis ($2,916 from Table 25.2), because the numbers in the sample were too small. When it is added to the above, a total damage value of $93,757 is produced or $315.68 per fisherman, which when multiplied by the parent population of 3380 respondents produces total damages of $1,066,998. These figures and those from Table 25.2 are too high, however, as the sampling method of Farmer and Billard gave too much weight to the results from the area where seal damage was more common.

Mansfield and Beck (1977) discussed seal damage to fishing gear as though it was mainly a grey seal problem, and Zwanenburg and Beck (1981)

Table 25.2
Value of Seal Damage ($) to Fixed Gear for Sample (N = 297) along the East Coast of Nova Scotia in 1983

Gear	No. Units Used by Sample Population	Repair Costs Caused by Seal Damage		Replacement Costs of Lost Gear Caused by Seals	Total Costs
		Labour	Material		
Fish traps	8	1,645	1,271	–	2,916
Mackerel–herring gill nets	1,322	11,210	15,431	8,631	35,272
Groundfish gill nets	597	202	988	6,882	8,072[a]
Wooden lobster traps	36,449	5,519	1,987	16,439	23,945
Wire lobster traps	536	–	–	–	–
Longlines	1,771	–	–	–	–
Total		18,576	19,677	31,952	70,205

Source: Farmer and Billard (1985).

a. Error corrected in source.

called their 1978 survey a grey seal damage survey. Farmer and Billard's (1985) sample of fishermen did not report separately on damage by harbour and grey seals, but these authors found a far greater amount of seal damage to gear in the area from east of Halifax to Cape Breton Island. They attributed this to the post-whelp fan of grey seals which migrate especially into this eastern part of the outer Atlantic coast of Nova Scotia from their large colony on Sable Island. Grey seals were about six times as numerous as harbour seals on Sable Island in 1973 (Boulva and McLaren, 1979), and their present population in the Atlantic provinces is three to six times that of harbour seals. (See Chapter 21.) Grey seals are much larger, being at least twice as heavy as harbour seals, and they migrate widely. It is to be expected, therefore, that most of the seal damage, both in the area of Nova

Scotia adjacent to Sable Island, and in the Maritimes area generally, should be due to the grey seal.

The EFF survey is the most recent and the most extensive in both area and detail, and it provides the best base for an attempt to extrapolate to unsurveyed areas. It is not easy to go beyond these studies to obtain estimates of the total losses for Nova Scotia, or even of the losses resulting only from gear damage for Nova Scotia. An extrapolation based on the relative amounts of the various kinds of stationary gear for the outer coast of Nova Scotia in 1983 and the Gulf area of Nova Scotia in 1982 (for which the 1983 data were not available; data supplied by DFO Halifax) adds \$140,000 to the \$799,000 derived from Table 25.2, or a total gear damage loss due to seals for Nova Scotia of \$939,000 in 1983. For the econometric analysis the additional proportional loss for the Gulf area would be \$174,000, bringing the total for Nova Scotia to \$1,241,000.

A number of factors affect these amounts. Not only was part of the outer coast of Nova Scotia not covered in the EFF survey, but 294 fishermen were also rejected from the population because they used their fishing licences on an incorporated basis and probably had larger than average operations. Furthermore, most of the Gulf area of Nova Scotia is in a region influenced by a breeding colony of grey seals approximately as large as that on Sable Island, and thus the extrapolation for that area might better be based on the part of the EFF survey area with greater seal damage rather than on the total outer coast area. These factors would all suggest that the total estimates for Nova Scotia are too low. On the other hand, the calculations of Farmer and Billard (1985) give too much weight to the results from areas of high seal damage, and this would suggest that their estimates are too high. At present it is impossible to resolve these unknown factors. It does appear, however, that the damages for Nova Scotia could be a million dollars or higher per year.

New Brunswick

The total value of New Brunswick's catch taken by stationary gear, amounting to \$58 million, is less than the values for Nova Scotia and Newfoundland, but since there is less trawling for fish in New Brunswick than in the other two provinces, these types of gear account for a greater proportion, that is, some 75% of the total value. Traps, mostly for lobster and crab, are economically the most important of the stationary gear, but signifi-

cant quantities of fish, amounting to some 50% of the weight of the total catch, are taken in weirs and gill nets (Northridge, 1986). Important differences, including the impact of seals, exist between the fisheries in the Gulf of St. Lawrence and the Bay of Fundy.

The New Brunswick Department of Fisheries (1985) stated that on the Gulf of St. Lawrence coast of New Brunswick, seals (presumably harp seals) cause damage in winters when the ice is scarce. At those times seals often come inshore and feed on smelts caught in set nets, causing loss of catch and damage to nets; typically, however, ice is more prevalent in winter, and these attacks do not occur. There is no information about the damage, if any, caused by seals at other seasons. In the Bay of Fundy, seals – either grey or harbour or both – are present all year-round and cause destruction of gear and catch. Gill-netted fish are eaten from the nets and seals are sometimes caught in the nets, causing serious damage. Seals eat fish from longlines, often leaving only the head attached to the hook. Lobster traps are badly damaged by seals seeking the bait that they contain. Seals attack fish in herring weirs, either by making holes in the twine or by passing through the door of the weir. The yearly cost of these various forms of direct damage caused by seals has not been estimated for New Brunswick, but in the Gulf, the major lobster fisheries and gill-net fisheries of that province are much farther from grey seal breeding colonies than are the fisheries of most of Nova Scotia. A subjective impression from the nature of the complaints from the two areas and their distances from the grey seal herds is that the damage per gear unit may be at a rate of about half that of Nova Scotia. Taking into account the relative values of landings from stationary gear in New Brunswick and Nova Scotia (Table 25.1) and allowing the rate of New Brunswick damage to be half that of Nova Scotia, the New Brunswick gear damage loss to seals would be about one-third that of Nova Scotia.

In previous years, when the salmon fisheries were more important than they are now, interference by seals was a major problem. In the estuaries of rivers such as the Miramichi in New Brunswick and in the southern part of the Gulf of St. Lawrence, seals, especially the grey seal summer concentration in the area, formerly interfered greatly with the gill-net fishery for salmon so that the nets had to be watched continually for seal interference and often taken up at night (Mansfield and Beck, 1977). Seals were also controlled by shooting those that went near the nets. The overall importance of seal interference with salmon and salmon nets has been greatly reduced by the decline in numbers of salmon and reduction or elimination of salmon fishing in many areas.

In the winter of 1983–1984, grey seals attacked aquaculture cages in the Bay of Fundy where Atlantic salmon and rainbow trout were being grown for market (N.B., Dept. of Fisheries, 1985). The seals made holes through the twine of the cages, passed into the cages, attacked many of the fish, and allowed many of the remainder to escape through the holes in the net. They attacked about 75% of the aquaculture net operations. Damage estimates are available for only one of the largest operators, who suggested that the overall loss may have approximated $500,000 in material, labour and lost stocks. A new wire cage design is being tested in the area, but the device is expensive and much more difficult to handle than twine. In addition heavier twine is being used to prevent the success of seal attacks. Salmon aquaculturists maintain a careful watch for grey seals, which are much larger and more powerful than harbour seals, with a view to shooting them. Beck and Stobo (1985) reported that heavier twine is now being used for the aquaculture cages, and that they were not aware of any seal damage incidents with aquaculture cages in the winter of 1984–1985.

Prince Edward Island

The fishing in Prince Edward Island, like that in New Brunswick, is dominated by stationary gear. Some 70% of the provincial catch, in terms of value, is taken by lobster pots, though significant quantities of fish, in terms of weight, are taken in gill nets. The fisheries are therefore potentially vulnerable to seal damage. In a brief to the Royal Commission, the Prince Edward Island Department of Fisheries (1985) stated that the grey and harbour seals have become a considerable nuisance to P.E.I. fishermen, and that gear loss from seals is a major economic consideration. The southeastern part of Prince Edward Island is close to a major breeding ground for grey seals. No detailed estimates of seal damage are available for the Island, though it may again be reasonable to assume, as a rough guide to the likely figure, that the rate of damage is somewhat similar to that experienced in Nova Scotia. On the basis of the location of Prince Edward Island in relation to numbers of grey seals and the value of the Prince Edward Island catch in stationary gear relative to the N.S. catch, the gear losses due to seals in Prince Edward Island may be about one-third those of Nova Scotia.

Quebec

Although trawling for fish and shrimp is relatively more important in Quebec than in New Brunswick or Prince Edward Island, stationary gear accounts for about half of the total Quebec catch in terms of weight and value. By weight, gill-netting for cod, flatfish, herring, mackerel and salmon accounts for more than half the 1983 total catch by stationary gear (Northridge, 1986).

No information on gear damage by seals is available from Quebec; but because the average density of grey and harbour seals is probably less than elsewhere in eastern Canada, the extent of damage may be small. The greatest density of seals occurs with the migration of the Gulf herd of harp seals. Little or no fishing is done when these seals are breeding, but as they migrate north along the north shore of the Gulf, there may be interactions, possibly similar to those noted in the most recent years in Newfoundland. In the summer there may also be some interactions with grey seals, especially close to the colony in the Magdalen Islands, and with harbour seals. Overall, given the relatively low total value of the catch by stationary gear, the total damage caused by seals in Quebec is probably much less than that caused in the Atlantic provinces.

Newfoundland

Slightly less than half of the value of the Newfoundland catch is from stationary gear and the proportion caught in pots is relatively small. Most of the catch comes from gill nets and fish traps.

One would expect to find that gill-net and cod-trap fisheries along the south coast of Newfoundland are affected by the moderately large summer concentration of grey seals on Miquelon Island, by other migrating grey seals from Sable Island, and by local colonies of harbour seals. On the contrary, the main complaints the Royal Commission has heard concerning gear damage or direct interference with fisheries by seals are in respect to juvenile harp seals on their spring migration northward from the breeding areas.

The Hon. W. Rompkey (1985), stated that, early in 1984, fishermen in his constituency of Grand Falls–White Bay–Labrador reported that an

increased number of seals, mainly beaters several months old, were being caught in their nets. One White Bay fisherman caught 38 beaters and bedlamers in his gill nets in one day. Barker (1985) of Knight's Cove, Bonavista Bay, stated that in early May 1985, juvenile harp seals were seriously interfering with the gill-net fishery for lumpfish (harvested for lumpfish caviar). This fishery uses large-mesh nets, and its fishermen are finding increasing numbers of young harp seals in their nets. As many as nine have been caught; they had rolled up and drowned in one net, causing much damage to nets, and greatly reduced catches of lumpfish. Similar complaints about greatly increased numbers of young harp seals caught in gill nets were reported from the Newfoundland Gulf coast in late April and early May 1985 (Lien, 1985). These increased damages to gill-net fisheries by young harp seals are presumably related to an increased number of young seals accounted for by the reduced kill of whitecoats in 1984–1985. Large seals might break through a light net, whereas the small seals might be caught in it and drown. In the Newfoundland area, in early summer, most gear losses are caused by whales, especially by humpbacks feeding near the coast on capelin, and losses caused by seals may pass unnoticed unless the seals are caught in the nets.

It does not appear possible to estimate the costs of seal damage to Newfoundland fishing gear with any accuracy. The incidence of seal damage in Newfoundland appears to be less than that in Nova Scotia, and the total damage costs are probably not greater than those in New Brunswick and Prince Edward Island.

British Columbia

Traps are of relatively small importance along the Pacific coast, where the important stationary gears are gill nets for salmon and herring. Lines are also important, and because the individual fish (halibut or salmon) are often valuable, they are potentially more vulnerable to seal attack than those on the Atlantic coast. The situation is also different because of the presence of numbers of eared seals (fur seals and sea lions) and relatively fewer true seals (only harbour seals).

Fisher (1952) found that damage to gill nets from harbour seals in the Skeena estuary was negligible. The loss of salmon to seal attacks on salmon caught in gill nets was at its worst in the early part of the fishery for chinook salmon, when it could amount to 12% or more of the value of the catch.

The Prince Rupert Fishermen's Co-operative Association (1985) stated that harbour seals will swim along a salmon gill net, biting and pulling at the gilled salmon. Fish remaining in the net are often maimed and thus unsaleable. Steller sea lions will rip all fish from a net, making holes of considerable size. Fishermen who troll for salmon have problems with sea lions removing fish from their lines. This brief also blamed California sea lions for damage to the nets of herring fishermen in the Strait of Georgia and to salmon farms there and in Barkley Sound.

In a summary based on data collected by Mate (1980, in IUCN, 1982), losses of $54 for damaged fish and an estimated loss of $22 for damaged gear per salmon gill-netter in Hecate Strait, B.C. for May–September 1962 were attributed to the Steller sea lion. Examples of damage in adjacent areas caused by this sea lion to gear and to fish of species that are also caught by Canadians were recorded as follows: 20%–30% of the Japanese catches of black cod in the Bering Sea south of the Pribilofs suffered damage; log books for 58 vessels fishing Pacific halibut in the north Pacific in 1958–1960 showed 8.1% of the fish damaged or destroyed and losses for the whole fleet estimated at $500,000; salmon gill-net fishermen from Copper River, Alaska, in 1977 had 8.3% (30,688) of their fish damaged, which represented a loss of $517 per boat or $230,000 for the 445 boats in the fishery, and suffered gear damage in the amount of $162 per boat or $72,000 for the fleet.

The California sea lion has caused damages estimated as high as $122,000 annually to the catch of the salmon-troll fishery in California (Mate, 1980, in IUCN, 1982). In recent years this sea lion has become more plentiful and presumably behaves similarly in its migrations northward. In the Columbia River, salmon severely damaged by the harbour seal – which is probably also increasing in U.S. waters as a result of the United States *Marine Mammal Protection Act of 1972* – amounted to 15% of the catch in test fishing in 1976 and 30% in 1977; unsaleable salmon represented 5% of the catch in 1976, and 12% in 1977, though two years' data are not enough to establish a trend (Mate, 1980, in IUCN, 1982).

Because of the lack of any recent survey information like the Atlantic coast surveys already referred to, only crude estimates can be made of gear and related fish losses caused by seals and sea lions in the Canadian Pacific region. The greatest losses seem to be the result of removal of fish from gill nets and associated damage to the gear. The losses given above, in terms of average losses per gill-netter, seem to be rather lower in British Columbia ($76 in 1962), than in Alaska ($679 in 1977), even allowing for inflation. These differences seem reasonably consistent with the relative den-

sity of seals in the areas. Taking the B.C. figure and allowing for inflation to produce a loss per boat of about $300, the total losses to the whole B.C. salmon gill-net fleet of some 2,300 vessels could be of the order of $700,000 for 1985. However, seal and sea lion densities have been quite variable in space and time along the B.C. coast (including effects from Steller sea lions from Alaska on the northern B.C. coast, and a new influx of California sea lions on the southern B.C. coast) so that it is unwise to place much reliability on this estimate which is based on data gathered from a relatively small area of northern British Columbia in 1962.

Northeast Atlantic

There is also information available from the United Kingdom and Norway on the damage done to fisheries by Atlantic species of seals. Rae (1966) reported severe damage by seals to cod in the Scottish cod-net fishery, vessels from which had dumped at sea many boxes of badly mutilated cod. Some seal-caused damage to nets, the stripping of fish such as mackerel from hooks, and the removal of bait from lobster traps were also reported.

Rae and Shearer (1965) studied the damage done by seals, especially grey seals, to the Scottish salmon-net fishery. The amount of seal damage to the coastal nets ranged from less than 5% of the nets at some stations to more than 30% at others. Many mutilated salmon, including some of which only the heads remained, were observed in the nets or washed ashore, and many clawed or tooth-marked salmon were seen. In four weeks' observation of drift netting for salmon, it was determined that 24% of the salmon caught off the River Tweed in February 1963 were damaged by seals. Many salmon must also have been removed from the nets.

Parrish and Shearer (1977) reported that the incidence of seal damage to salmon bag and stake nets in Scottish waters decreased markedly during the 1960s, and by the mid-1970s very little net damage was reported. The decrease was attributed to the increasing use of the stronger synthetic twines in these nets. A few stations still showed some net damage. Damage to netted salmon showed no apparent trend at most Scottish stations between 1964 and 1976, in spite of a great increase in numbers of grey seals, but damage did increase at a few stations. Damage was highest in the spring run of larger salmon, possibly due in part to seals only taking bites from such salmon and leaving evidence in the nets that they had done so. Some of the smaller salmon, the grilse, which were mainly caught later in the year, may

have be taken completely from the net by seals and the damage not observed. The average loss in value from damaged salmon was estimated at less than 1%, but this figure does not include fish, especially the smaller ones, which may be taken from the net or eaten completely and thus not noted as damaged fish. Stansfeld (1984) remarked, however, that in the late 1960s and early 1970s, the salmon run changed substantially in favour of larger grilse runs and fewer large salmon; he noted, too, that grilse were later than large salmon in returning to rivers. The lack of large salmon was presumably the result, in the main, of the west Greenland netting of the larger salmon returning in the second or later years of sea life; the grilse, on the other hand, are not affected by the Greenland fishery. The data of Parrish and Shearer (1977), mentioned above, combined results from salmon and grilse, rather than expressing the numbers separately. The percentages of seal-damaged salmon and grilse were much higher in the period up to 31 May, when salmon are relatively more plentiful, than they were in the predominantly grilse period from 1 June onward.

The International Council for the Exploration of the Sea (ICES) working group on interactions between grey seal populations and fish species (ICES, 1979) reported that the damage to the salmon catch has been monitored in Scotland since 1964, but that there has been no significant change in the level of grey seal damage to entrapped salmon, estimated at 3%–5%. In drift-net experiments, at least 2.3% of the catch of 1,305 salmon were seen to be taken from the nets by grey seals.

Potter and Swain (1979) studied the incidence of predation by grey seals on salmon caught in commercial nets on the northeast coast of England in 1977. They concluded that seals removed about 5% of the salmon caught in the nets and damaged an additional 1%–4%, causing a total loss to the salmon netsmen in the area studied of about £30,000 in 1977.

Annual damages to net gear, especially gill nets and trap nets in Norwegian waters were estimated for 27 fishermen as 2,900 Norwegian Kroner (Nkr.) per fisherman (Bjørge et al., 1981.) The reported percentages of damaged salmon (for 34 salmon fishermen) averaged 15% in areas with concentrations of grey or harbour seals. More than 10,000 harp seals were reported to have drowned in gill nets in northern Norway in each of the years from 1979 to 1981. The costs of gear damage caused by these harp seals were estimated at Nkr. 610,000 in 1979, and Nkr. 980,000 in 1980.

With the decline of several of the natural stocks of salmon, the significance of some of the types of seal damage described above may be de-

creasing. At the same time increasing attention is being paid to the culture of salmon, especially in Norway, but also in the United Kingdom. This type of operation is, in principle, vulnerable to damage by seals, and has been examined in a recent review by the U.K. National Environment Research Council (Thompson et al., 1984).

Questionnaires returned by 14 establishments with cages in the sea all reported some activity of both grey and harbour seals. Damage ranged from nil to frequent, or even daily, loss of fish, mostly caused by seals biting the fish through the net. There were two cases (over some years) of damage causing large-scale loss of fish. Seal damage appears to have been successfully kept in hand by deterrence (shooting), and by placing large mesh anti-predator nets outside the cages to entangle the seals or to prevent them from approaching.

Estimates of Total Loss

In the previous sections it was estimated that in the Atlantic provinces (excluding Quebec, where the damage seems small), seals cause damage to gear amounting to some $2 million annually. To this figure should be added the losses represented by fish escaping from damaged nets or being eaten or damaged by seals, the effects of lost fishing time, and the losses to aquaculture operations. Some information is available about fish losses from gear in the west coast fisheries, and how these values compare with gear damage. The information presented earlier for salmon gill nets produced ratios of 2.5:1 ($54:$22, B.C.) and 3.2:1 ($517:$162, Alaska) in terms of the value of lost fish to the cost of gear damage by sea lions. These ratios are not necessarily typical of all types of seal-fisheries interactions. In particular, they do not relate to the interactions with lobster pots. The impression given by submissions is that lobster fishermen are at least as concerned about removal of bait (and thus about loss of effectiveness of their gear) as they are about damage (e.g., N.B., Dept. of Fisheries, 1985; Lobster District 4B Working Group, 1985).

Losses to the individual fishermen through reduction in gear effectiveness or lost fishing time may not represent the net loss to the Canadian fishing industry as a whole. Lobsters and many fish stocks are heavily exploited. Therefore, if one fisherman fails to catch a lobster because a seal has removed the bait from his trap, that lobster may still be taken by the same or another fisherman in the same fishing season. Similarly, the effect of lost

fishing time on the total Canadian catch will be small if the stock is heavily fished, with the result that the changes in fishing effort produce little change in total yield.

The total impact on Canadian catches, taking all factors into account, is greater, therefore, than the impact of gear damage but not as great as the individual fisherman might believe on the basis of his own experience of encounters with seals. The loss to the individual fisherman may nevertheless be considerable, if his operation is particularly vulnerable to seals. If seals are interfering with his gear, it is no consolation to the individual that someone else is catching the fish.

It is thus impossible to put a figure on the additional costs. For the present it seems best to confine attention to the costs of actual damage, which amount to about two million dollars annually in eastern Canada, but to bear in mind that these costs should really be larger, since the figure named above has not included fish not caught while the gear is not working, fish damaged in the nets by seals, fish taken from the nets by seals for food, or damage to aquaculture operations.

At the same time, it must be recognized that the data base from which the total cost figure was obtained is extremely poor. It is satisfactory for providing an indication of the probable extent of the problem, but much better information should be collected, probably along the lines of the survey already made in parts of Nova Scotia. This undertaking should not only provide a better estimate of the total impact of seals on fishery operations, but should also enable a much sharper identification of the particular areas and types of fishing gear that are more seriously affected. Such information, in turn, might help policy makers to form a better evaluation of various possible approaches to a reduction of the problem and to determine, especially, whether there are feasible approaches that do not involve extensive and large-scale culling of seals.

Approaches to Reducing Damage

Modification to the Gear

Lobster fishermen have modified their gear to minimize damage from seals. The modifications include putting boxes over the bait and using smaller rings which make it more difficult for the seal to get its head into the

trap, though this method may preclude catching "jumbo" lobsters (Farmer and Billard, 1985). Salted bait is not attractive to seals, and its use may reduce seal damage. At the same time, it may also be less attractive to lobsters.

Stronger materials will reduce damage to nets. Parrish and Shearer (1977) reported that damage to salmon nets in the United Kingdom was considerably reduced after the change to synthetics. In eastern Canada, however, seals damage or destroy synthetic gill nets used for herring and mackerel. These nets are made of thinner twine than are salmon nets. In the chief species-directed fisheries, herring and mackerel are now caught in purse-seines and weirs, but lobster fishermen catching fish for bait find that it is much more convenient to use a few gill nets.

Deterrence

Since the most serious damage occurs at fixed points, that is, in large fish traps or fish-culture pens, it may be feasible to deter seals from approaching. Various methods have been used, and the ultimate deterrent in this form of warfare, shooting, is popular. Rifle fire is undoubtedly effective, and even when the seal is not hit, a rifle shot can increase the time before another (or the same) seal is seen in the vicinity (Thompson et al., 1984). This method does, however, require someone to be on watch, and therefore can add considerably to labour costs. It also raises the question, discussed below, of whether it is proper for fishermen to shoot seals. Moreover, seals become wary and learn how to approach a net and how to catch their fish without exposing themselves very much.

A less drastic approach to deterring seals is the use of various acoustic devices to frighten the seals. The most extensive work on such devices has been done in South Africa (Shaughnessy et al., 1981), where Cape fur seals take large quantities of fish from purse-seines, with up to 500 seals entering one net. Tests were made using recorded killer whale sounds and other acoustic devices, but these sounds, apart from some initial reactions, proved ineffective in scaring fur seals. Similar results were reported by Anderson and Hawkins (1978) in the United Kingdom. Tests were also made using explosive fire-crackers, including the commercially produced Seal Deterrents. Research trials and the results of questionnaires both showed that these devices were effective, though several might have to be used in succession to scare all the seals from a net. A ban on these materials was introduced in South Africa in 1976, because they had "no adequate effect

on the seals and [their use] is extremely harmful to the shoals of pelagic fish" (Shaughnessy et al., 1981). However, as the authors reported, no evidence was produced for either of these somewhat surprising statements. Prior to the ban, some quarter of a million Seal Deterrents had been manufactured and sold between 1973 and 1975 which suggested that many fishermen did believe that they were effective. Shaughnessy et al. recommended the re-authorization of the use of Seal Deterrents.

A similar approach has been followed on the Canadian Pacific coast, where "seal bombs" have been used to frighten seals away from fishing gear. There are anecdotal reports that these can be fatal if accidentally or deliberately dropped very close to the seal, but there is no information on how widespread this practice is.

As with all use of explosives, there are obvious disadvantages to this method of seal control. At the high level of seal interference in South Africa, potential benefits can outweigh these disadvantages, but there is no indication, on presently available evidence, that such a method would be justified in Canada.

An alternative method is being examined by Dr. Mate of Oregon State University. This method aims to scare seals away from a fixed point such as the entrance to a salmon hatchery by producing an underwater sound the volume and frequency of which is highly unpleasant to the seal. There may therefore be less chance of the seal becoming used to the sound or, as appears to be the weakness of using recorded killer whale sounds, learning that, in fact, there is no killer whale and no reason to be afraid of the sounds. Preliminary trials in the United States and the United Kingdom are promising (Mate, 1985), but more studies are needed. An advantage is that seals apparently put their heads out of water to avoid the noise. This defeats any cautious submerged approach to a net, and makes the seals vulnerable to other countermeasures such as shooting.

Changes of Gear

Some types of gear used in Canada are relatively invulnerable to seals. Where a change can be made from a vulnerable to a less vulnerable type of gear, the change provides a simple and permanent solution. It appears from the statistical tabulations that lobster is the only species taken in a vulnerable gear that is not also, perhaps at different times and places, taken in less vulnerable types of gear. For other species, where seal damage

does appear to be a problem, fishermen should be encouraged to change the type of gear wherever possible. This may involve providing grants to purchase new gear or to cover disruptions during the transition period.

Reduction in Seal Abundance

It would be reasonable to expect that, other things being equal, damage by seals would be proportional to the number of seals present. Indeed, to the extent that increasing seal abundance could add to their pressure on their food supplies, it might cause the individual seal to be more anxious to take the bait from a lobster pot or fish from other fishing gear, and damage might increase faster than abundance.

The supposition of proportionality is probably true as it relates to accidental encounters with the gear, an example of which is the increased entanglement of young harp seals observed in the last few years. Many cases of damage, however, may well occur as a result of the deliberate act of a seal in approaching the gear to take fish. It seems reasonable to suppose that the habit of taking fish from traps or gill nets is not spread evenly through the seal population. The extent of damage will then be more closely linked to the number of these "rogues" (though this may not be the best term to apply to them) than to the overall abundance. In that case, making reductions in the total abundance of seals may not be the most effective way of reducing the number of "rogues" or the damage they cause. The problem of reducing the negative effects of seals on fisheries by some form of population control is discussed further in Chapter 29.

The most drastic approach to reducing the number of "rogues" was formerly used in Scotland, where strychnine was placed in dead fish which were then placed in the nets. This method certainly was effective in killing seals, but it was inhumane and could result in the poisoning of other marine life. It has been banned in Scotland, and it should not be used in Canada. Shooting can also be effective in reducing the number of "rogues", and if carried out properly, should carry little risk of inflicting undue pain. (See Chapter 20.)

Discussion

Damage to gear and loss of fish are highly visible, and in most cases it is clear that the damage is done by seals, though occasions when seals

may be used as scapegoats for bad weather or other animals should not be ignored. The extent of losses, expressed as a percentage of the total value of Canadian fisheries, is very small, but losses are concentrated in certain places where they can represent an appreciable part of the income of some individual fishermen. If no action is taken, these losses can be expected to increase as the stocks of grey seals (which appear to be the main source of loss in eastern Canada) and other species increase. It is possible that seal stocks will stabilize at equilibrium levels before losses pose a serious threat to the livelihoods of fishermen. Nevertheless, it is asking a great deal of fishermen to expect them to accept an increasing loss without government taking some action in their interest or allowing them to take action themselves. In evidence before the Royal Commission, most spokesmen for fishermen made it clear that while they accepted the presence of some seals and the losses that the seals cause, they believed that some action had to be taken to prevent an unlimited increase in seal populations (e.g., Fisheries Association of Newfoundland and Labrador Limited, 1985; Fisheries Council of B.C., 1985). The Fisheries Council of Canada (1985) declared explicitly that its members believed that the abundance of grey seals was approaching the limit of acceptable numbers.

The evidence on the current level of seal damage (especially on the extent of very serious loss to fishermen's livelihoods), on the degree to which this damage would increase if no measures were taken to control the seal population, and on the effectiveness of culling or bounty programs, is insufficient to justify government engagement in such programs on the basis of gear damage alone. This evaluation might change if the combined effects of gear damage, nematode parasites and competition for fish are taken into account. (See Chapter 29.)

The Royal Commission is of the opinion, however, that fishermen who have reason to believe that they are suffering particularly from seal damage should be allowed to take some action. This action could take the form of shooting seals seen in the vicinity of certain types of fixed gear. Permission to take this action should be subject to conditions applying to the number of seals shot, and the type of gun and ammunition used, so as to minimize the chances of the seals suffering and the risks to other persons present. Measures should also be taken to encourage the reporting of material (e.g., lower jaws) and information that will assist research into seals and their dynamics.

Conclusions

1. Seals remove fish from nets and other gear, take bait from lobster traps, and damage gear either in taking fish or from accidental encounters. The annual losses for gear damage alone in Atlantic Canada could be $2 million or more. The costs of gear damage and loss of fish on the Pacific coast may be considerable, especially to salmon gill-netters (where the loss may be $700,000 annually), but the total loss cannot be estimated with any precision. The estimates of damage and loss are very approximate, and more data are needed to increase their precision and to determine total losses due to seals.

2. This damage, while small in relation to the total Canadian fish catch, is concentrated in certain areas and certain types of gear. The most vulnerable types of gear are gill nets, fixed traps and fish-culture cages. For the fishermen most affected, the damage can represent a threat to their livelihood.

3. Damage on Canada's east coast is probably caused primarily by grey seals, and to a lesser extent, by harbour seals. In the last couple of years, entanglement of young harp seals in bottom gill nets has become significant around Newfoundland. On the west coast damage has been caused by harbour seals and both species of sea lions.

4. Damage can sometimes be reduced by modifications to the fishing gear, such as the use of stronger twine in gill nets, but this remedial approach is not feasible in all situations.

5. Other things being equal, it must be expected that increasing seal numbers will be associated with increasing damage. However, because many of the destructive encounters are the result of individual seals learning where they can obtain fish, other factors may be equally or more important than overall seal abundance. No significant relation was found in a Scottish study between increasing numbers of grey seals and the rate of damage to salmon in gill nets.

6. A number of methods of controlling the extent of seal damage, ranging from shooting to acoustic scaring devices, have been used to protect fixed nets and fish-culture operations. The success of these methods has been variable.

Recommendations

1. Further data should be collected to identify more precisely, according to time, place, and type of gear, the fishing operations that are particularly vulnerable to seal damage, and the specific situations in which increased seal damage would pose a threat to the continuing economic viability of an operation.

2. In the interests of threatened operations, studies should be made of possible technical means, such as modifications to the gear, that would reduce both damage caused by seals and the level of incidental mortality caused among them.

3. Further studies should be made of the degree to which damage may be directly related to overall seal abundance. These should include attempts to identify whether particular individual seals are involved in a relatively high proportion of incidents.

4. The impact of seals on fishing operations should be taken into account in determining the desirability of controlling the populations of seals. (See Chapter 29.)

5. Bearing in mind the localized nature of much seal damage, operators of fixed gear and of fish-culture operations may be licensed, subject to appropriate controls, to shoot strictly limited numbers of nuisance seals which closely approach these operations, with provision for a reward for return of biological material of value to research programs.

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Chapter 26

Transmission of Parasites

Recent study of the incidence of sealworm . . . indicates that this parasite has become far more abundant in cod in the eastern Scotian Shelf area and Sydney Bight than it was 25 years ago (Fisheries Council of Canada, 1985).

Introduction

Infection of fish with nematodes (roundworms) is a major problem facing the commercial fishing industry along the eastern coast of Canada. Larval nematodes occur in the flesh of many commercially important fish species and make fillets unsightly and unappealing to consumers. To improve marketability, attempts are made to remove these parasites from fillets but this is a costly process. In some cases, levels of infection are so great that entire catches cannot be sold. While a number of nematode species are involved, the most important is one that matures and reproduces in seals, the usual definitive or final host of the parasite. Since numbers of this parasite are often thought to be proportional to numbers of seals, especially grey seals, it has been suggested that control of seals is a means of controlling intensities of infections in fish.

Several species of nematodes mature in the stomach or gastrointestinal tracts of marine mammals; some of these species use fish as an intermediate host and are consumed by the marine mammal as part of its normal diet. Most of these nematodes are not important to the present problem because they encyst within the body cavity of fish. However, *Pseudoterranova decipiens* (*P. decipiens*) and *Anisakis* spp. (usually *A. simplex*), commonly occur in the flesh of fish. *Anisakis* is a small whitish or flesh-coloured nematode, whereas *P. decipiens* is considerably larger and of greater bulk. In addition, the latter species is yellowish and sometimes reddish-brown in colour, making it much more visible to the consumer. In areas where there are great numbers of *P. decipiens*, these nematodes are much more abundant than *Anisakis* in the fillets. Thus *P. decipiens* usually presents the chief problem in the marketing of nematode-infected cod and

other groundfish, especially when filleted (Templeman et al., 1957). Moreover, its final host is typically the seal, whereas the usual final host of *Anisakis* is a cetacean. Because of the specific objectives of the Royal Commission, information is presented on *P. decipiens*, except when it is necessary to mention the relative importance of *Anisakis*.

This chapter examines the following points:

- the life history of *P. decipiens*;
- its occurrence in seals and fish;
- temporal changes in infection rates;
- relationship between the species and numbers of seals and infection rates in fish;
- dangers to human health;
- costs of parasitism to the fishing industry;
- options for dealing with the parasite problem.

The taxonomy of *P. decipiens* is briefly reviewed in Templeman (1986). *P. decipiens* has been called either codworm or sealworm, but will be referred to here by its scientific name, *Pseudoterranova* (or *P.*) *decipiens*. The genus *Pseudoterranova* has formerly been treated as *Phocanema, Terranova* or *Porrocaecum*.

Parasites

Nematodes, or "roundworms", are a highly successful and extremely widespread group of animals. They have a simple, smooth, cylindrical, non-segmented body structure, easily distinguishable from other worms. Free-living forms occur in soil, and in fresh and salt water; parasitic forms infect most organs of many species of plants and animals. *Pseudoterranova decipiens* and *Anisakis simplex* are nematodes of the suborder Ascaridata, of the Anisakidae family, which are relatively large nematodes. Ascaridoids are dioecious (i.e., the sexes are separate) and the adults normally feed on the intestinal contents of the host, as well as on mucus and discarded intestinal cells. All nematodes undergo a series of four moults after hatching before reaching maturity.

Life-Cycle

The representation of the life-cycle of *P. decipiens* in Figure 26.1 gives the reader a broad idea of how the nematode is transmitted from host to host. A more detailed description of the process follows, taken primarily from McClelland et al. (1983a).

The eggs of *P. decipiens* are 45–50 micrometres in diameter when passed out in the faeces of the seal. They settle in sea water, adhere to the substrate and develop to the second, or possibly the third, larval stage within the egg in 8–52 days, when they hatch. Development and hatching are known to occur at temperatures as low as 2°C. The larval nematodes, which are about 200 micrometres in length at hatching, anchor themselves to the substrate by their caudal extremities. The post-hatch survival period for these free-living larvae ranges from about two days at 20°C to 140 days at 5°C. It is thought that these larvae are usually eaten by bottom-related or free-swimming copepods of the suborder Cyclopoida or Harpacticoida, although no naturally infected copepods have been found. In the body cavity (haemocoel) of experimentally infected copepods, the nematodes grow 60%–130% in length in 7–35 days, depending on temperature. They do not moult or undergo significant morphological changes in the copepod host.

Known natural second intermediate hosts for *P. decipiens* include crustaceans (amphipods, cumaceans, decapods, isopods and mysids), polychaete worms and nudibranch molluscs, but infection probably occurs in many other benthic macroinvertebrates that eat infected copepods. Under experimental conditions, larval *P. decipiens* grow rapidly in the amphipod haemocoel, reaching 2–3 millimetres in length within 30 days at 15°C, 60 days at 10°C and 140 days at 5°C. The nematode reaches 7–10 millimetres after 90 days at 15°C. In amphipods, *P. decipiens* becomes sexually differentiated and can reach the stage where it may be directly infective to seals, completing its life-cycle without a fish host (McClelland et al., 1983a). The relative importance of this pathway is, however, unknown.

Larval *P. decipiens* more than 2 millimetres long infect fish that eat infected invertebrates (or fish containing the parasite). The larvae escape from the partially digested food and in two to three hours penetrate through the stomach wall into the body cavity or visceral organs of the fish. After 24 hours many will have reached the muscles of the fish, where they continue to grow up to a length of 50–60 millimetres. They then become encysted in the flesh of the fish, where some die, but most remain alive and potentially infective.

Figure 26.1

Life Cycle of the Parasitic Nematode *Pseudoterranova decipiens*

Adult *P. decipiens* are found in the stomach of the seal. Eggs are passed out in seal faeces, hatching into larvae which attach to the bottom substrate.

Larvae are eaten by benthic, epibenthic and free-swimming copepods. Larvae within the haemocoel of the copepod do not moult or significantly change in form.

Copepods containing *P. decipiens* larvae are eaten by amphipod, isopod, polychaete, or other macroinvertebrate hosts. Larvae grow in the haemocoel of crustaceans, the coelom of polychaetes and the visceral mass of molluscs.

Mainly benthic macroinvertebrates containing *P. decipiens* larvae are eaten by small fish. Larvae invade the body muscles of fish.

Small fish or mainly benthic macroinvertebrates containing *P. decipiens* larvae are eaten by larger fish. Larvae then migrate to body muscles of fish, and after attaining their full growth in the fish, they encyst.

Larger or smaller fish or macroinvertebrates containing infective larval *P. decipiens* are eaten by the seals.

Source: Adapted from McClelland et al. (1983a).

When fish or invertebrates infected with larval *P. decipiens* are eaten by seals, the parasite escapes from the tissues of the intermediate host and attaches itself to the stomach wall of the seal. The larvae again moult, twice, and become sexually mature adults at lengths of about 80 millimetres (female) or 65 millimetres (male). The female contains between 200,000 and 500,000 eggs, and may lay several thousand daily; these are passed out in the seal's faeces to repeat the cycle. The average life span of an adult *P. decipiens* is about 35 days.

The life cycle of *Anisakis simplex* is similar to that of *P. decipiens*, except that the first intermediate host is a euphausiid, and the definitive host is usually a whale or porpoise, although seals may also be infected.

Parasite Hosts

As discussed in the previous section, the first and second intermediate hosts of *P. decipiens* are probably copepods and benthic macroinvertebrates respectively. Little is known about naturally occurring infections of the parasite in these hosts. The following discussion deals with the occurrence of the nematode in the third intermediate hosts (fish) and the final hosts (seals). Larval nematodes in fish and immature specimens in seals are generally not identified to species, as they do not possess the necessary structures for positive identification, but it can be assumed that specimens referred to as *Pseudoterranova* sp. larvae are *P. decipiens*, as this is the only species of the genus identified in the areas under discussion.

Mammalian Hosts

The final, or definitive, host of *P. decipiens* is normally a marine mammal, particularly grey, harbour and harp seals (Table 26.1). Grey seals are typically most heavily infected, with 3–13 times as many parasites as harbour seals and up to 74 times as many as harp seals (Scott and Fisher, 1958b; Mansfield and Beck, 1977). Other hosts for *P. decipiens* in both Atlantic and Pacific waters include bearded, ringed, hooded and northern fur seals, Steller and California sea lions, common porpoise, and white and sperm whales. In many of these incidental hosts, infections are of low density, and the nematode is often immature.

Table 26.1
Mean Numbers of *P. decipiens* in Stomach or Gastrointestinal Tract of Seals and Cetaceans[a]

Location	Period	No. of Seals	Mean No./Seal Adult	Mean No./Seal Immat.	Ref.
Grey Seal					
Northwest Atlantic					
Sable Island, N.S.	1983–84	162[b]	(145)+	(374)+	1
	1949–56	3	48	35	2
Ecum Secum, N.S.	Jan–Feb 1975–78	19	76	461	3
	Apr–Jun 1975–78	6	196	521	3
	Sep–Oct 1975–78	5	483	601	3
Amet Island, N.S.	Jan 1975–78	5	1	197	3
E Northumberland Strait	Sep–Oct 1975–78	9	389	351	3
Northumberland Strait, Gulf of St. Lawrence	N/A	49	212	640	4
E Cape Breton Island, N.S.	N/A	18	172	378	4
Miramichi Estuary, N.B.	1949–56	29	187	84	2
Bras d'Or Lakes, N.S.	1949–56	3	169	2727	2
NE Nova Scotia	1949–56	17	60	99	2
Northeast Atlantic					
N North Sea	1964	6	38	–	5
Orkney Islands, Scotland	Oct–Nov 1966	8	179	556	6

Table 26.1
Mean Numbers of *P. decipiens* in Stomach or Gastrointestinal Tract of Seals and Cetaceans[a] (continued)

Location	Period	No. of Seals	Mean No./Seal Adult	Mean No./Seal Immat.	Ref.
W Isles, Scotland	Sep–Oct 1966–68	9	38	97	6
	Mar 1969	2	4	17	6
Shetland Islands, Scotland	Feb–Apr 1969	10	8	17	6
E Anglia, England	Feb–May 1968	7	2	3	6
Iceland	1975–1977	6	188	507	7
Harbour Seal					
Northwest Atlantic					
Sable Island, N.S.	1983–84	39	42	181	1
	1949–56	2	9	2	2
Ecum Secum, N.S.	June–July 1975–78	5	2	79	3
Northumberland Strait, Gulf of St. Lawrence	1949–56	5	6	10	2
Magdalen Islands	1949–56	8[c]	8	88	2
Bras d'Or Lakes, N.S.	1949–56	5	43	308	2
NE Nova Scotia	1949–56	8	21	31	2
SW Nova Scotia	1949–56	1	11	63	2
Lower Bay of Fundy, N.B.	1949–56	76	13	34	2

Table 26.1
Mean Numbers of *P. decipiens* in Stomach or Gastrointestinal Tract of Seals and Cetaceans[a] (continued)

Location	Period	No. of Seals	Mean No./Seal Adult	Mean No./Seal Immat.	Ref.
Northeast Atlantic					
N North Sea	1970	1	0	45	5
Orkney Islands, Scotland	Oct 1966	1	17	28	6
W Isles, Scotland	Mar 1969	11	1	12	6
Shetland Islands, Scotland	Feb 1969	1	50	5	6
E Anglia, England	Apr–May 1968–69	6	0.8	1	6
Iceland	Jan–Feb 1975–77	5	74	175	7
	Mar 1975–77	8	45	68	7
	Apr–May 1975–77	15	12	42	7
	June–July 1975–77	3	6	12	7
	Nov 1975–77	5	30	23	7
Harp Seal					
Magdalen Islands	Mar–May 1956	195	0.4	4	8
	Mar–Apr 1954–56	61	0.03	5	2
	Apr–May 1952–56	237	5	10	2
Port Hood, N.S.	Feb 1950	4	110	140	2
Blanc Sablon	June 1953–55	274	0.2	0.1	2
E Coast Nfld./Lab.	Mar–May 1949–51	43	0	0.3	2
	Mar–Apr 1983	68	0	0	2
La Tabatière, P.Q.	Jan 1950	21	0	0	2

Table 26.1
Mean Numbers of *P. decipiens* in Stomach or Gastrointestinal Tract of Seals and Cetaceans[a] (continued)

Location	Period	No. of Seals	Mean No./Seal Adult	Mean No./Seal Immat.	Ref.
Common Porpoise					
Lower Bay of Fundy	1955–56	51	0	0.7	9
White Whale					
Mace's Bay, N.B.	June 1952	1	0	80	9
Sperm Whale					
S Denmark Strait	Aug 1967	3	0.3	0	6

References:
1. McClelland et al. (1985), McClelland (1985);
2. Scott and Fisher (1958b);
3. McClelland (1980);
4. Mansfield and Beck (1977);
5. van Banning and Becker (1978);
6. Young (1972);
7. Pálsson (1977);
8. Myers (1957);
9. Scott and Fisher (1958a).

a. Seals less than one year old and uninfected cetaceans are omitted.
b. Ninety seals averaging more than 2,000 *P. decipiens* each had not been analysed.
c. One highly parasitized seal not included.

N/A not available.

Geographical and Temporal Distribution

Infections by *P. decipiens* have been reported in most populations of grey, harbour and harp seals studied (Table 26.1), but it is apparent that great differences have been found in numbers of the nematodes, not only among species of seals and among areas, but also in a particular species of

seal in the same area at different seasons. McClelland (1980) reported, for instance, that grey seals at Ecum Secum, N.S., were infected with a mean of 76 adult *P. decipiens* in January–February, 196 in April–June and 483 in September–October. These periods correspond respectively to grey seal whelping, moulting and feeding periods. Immature nematodes were apparently not as much reduced during the fasting periods (whelping and moulting) as were the adults. In harbour seals, Scott and Fisher (1958b) found no obvious temporal variation in the total numbers of *P. decipiens*, except that the lowest numbers in the lower Bay of Fundy were found in July–August, during moulting. Pálsson (1977) examined harbour seals in Iceland and found mean adult *P. decipiens* infections of 74 in January–February, 45 in March, 12 in April–May (prior to whelping), 6 in June–July (when moulting may be taking place) and 30 in November (Table 26.1).

Available information thus suggests that infections of adult *P. decipiens* in seals are lower during non-feeding periods; it is possible either that the immature nematodes are not as sensitive to fasting of the host and are not lost to the same degree, or that development of the larva to the adult stage does not occur as readily when the hosts (and thus the parasites) are not feeding. In experimental and natural infections of fasting grey and harbour seals, the anterior ends of the nematodes were embedded in the stomach wall and the nematodes were less prone to being passed from the stomach. During feeding periods, adult *P. decipiens* tend to be free in the stomach, whereas immature stages remain attached to the stomach wall. Thus replacement of adult nematodes (which may have a shorter life span when food is scarce) would not occur until the host started to feed again.

Recent data from Sable Island indicate an increase in numbers of *P. decipiens* per seal (Table 26.1); however, lack of information on the months when seals were examined renders the information suggestive rather than conclusive. A small number of Sable Island grey and harbour seals examined in the 1949–1956 period contained mean numbers of 83 and 11 nematodes respectively (Scott and Fisher, 1958b); a larger number in the 1983–1984 period contained mean numbers of 519 and 223 respectively (McClelland et al., 1985). The 1981–84 data represent an underestimate of the actual mean numbers of nematodes per seal; they excluded 90 heavily parasitized grey seals which contained more than 2,000 nematodes each (McClelland, 1985).

Infection Rates

Studies involving the experimental introduction of known numbers of larval *P. decipiens* into the stomachs of grey and harbour seals (McClelland, 1980) have demonstrated that this nematode is better adapted to the grey seal than to the harbour seal (Table 26.2). Some of the differences between infections in grey and other seals may be attributable to the larger size of the grey seal: they are at least twice the weight and one and a half times the length of harbour seals, while harp seals are of intermediate size.

Table 26.2
Experimental Infections of Seals with ***P. decipiens***

Host	Adult Female *P. decipiens* at Six Weeks			
	% Survival	Length (mm)	Mean No. of Eggs per Female	Egg Production per Day
Grey seal	48	82	366,000	11,000–27,000
Harbour seal	9	61	156,000	3,000–11,000

Source: Data from McClelland (1980).

Fish Hosts

Species Infected and Geographical Distribution

Specific studies on larval infections of *P. decipiens* in fish have concentrated on commercially valuable species in the Atlantic Ocean, but low infections have been reported for many other fish in other regions. Canadian Atlantic records show infections occurring in Atlantic cod and other fish species in all divisions of Sub-areas 2, 3 and 4 of the Northwest Atlantic Fisheries Organization (NAFO) Convention Area (Figure 26.2), with the exception of Flemish Cap in division 3M, from which few fish have been examined specifically for nematodes. Fish species in eastern Canadian waters, other than Atlantic cod, which are known to be naturally infected by *P. decipiens*, include spiny dogfish, winter and thorny skates, rainbow smelt,

goosefish, Greenland cod, haddock, white hake, Atlantic tomcod, ocean pout, cunner, redfish, American plaice, longhorn, shorthorn, moustache and ribbed sculpins, sea raven, Atlantic halibut, and yellowtail, smooth, witch, winter and windowpane flounders (Margolis and Arthur, 1979).

Infections of the following species have been reported in the Pacific Ocean off British Columbia: Pacific cod, black cod, lingcod, Pacific halibut, rockfish, ocean perch, walleye pollock and sockeye salmon (Margolis and Arthur, 1979), and off Alaska: walleye pollock, Pacific cod, rock greenling and red Irish lord (Stiles and Hassall, 1899; Scheffer and Slipp, 1944; Schiller, 1954).

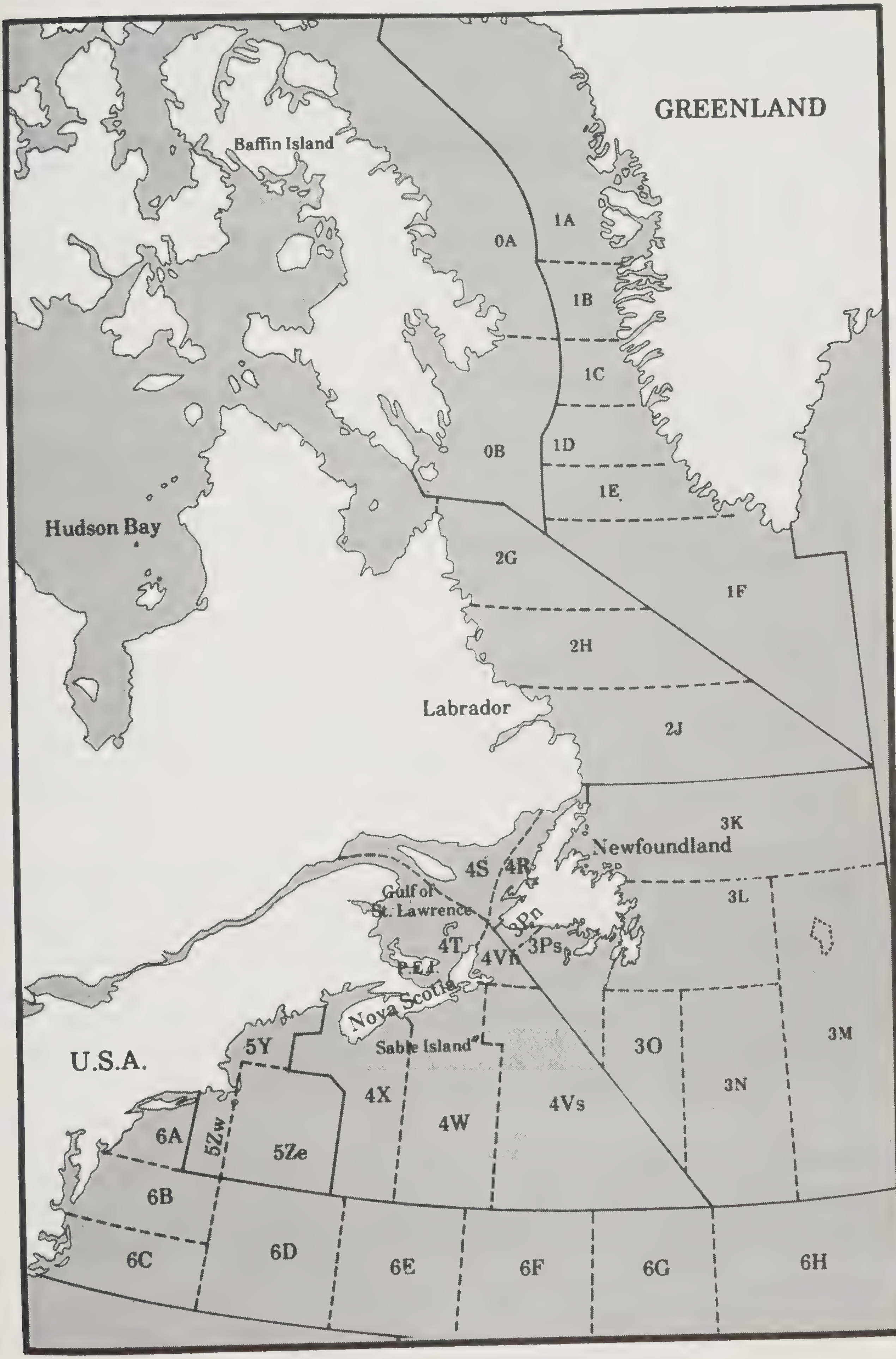
Heavy infections in European waters occur in Atlantic cod from the west coast off Scotland, the Irish Sea, the Bristol Channel, the west English Channel, the northeast coast of England, the Faeroe Plateau, Iceland and the southern coast of Norway (Young, 1972; Platt, 1975; Bjørge et al., 1981). Other fish species from Europe reported to have infections of *P. decipiens* include American plaice, witch flounder, haddock, whiting, poor cod and dragonet; the latter reports come from isolated inshore locations in Scottish waters (Wootten and Waddell, 1977).

Anisakis simplex has been identified in fish from the Pacific (Pacific hake) and from the Atlantic (alewife, Atlantic cod, Atlantic herring, Atlantic salmon, silver hake and Atlantic mackerel), and is probably the species usually identified as *Anisakis* spp. in capelin and many other species of fish in both the Atlantic and Pacific Oceans (Margolis and Arthur, 1979).

Location of Parasites Found in Fish

Infections of *P. decipiens* in cod are chiefly present in the fillets. McClelland et al. (1983a), when studying Atlantic cod taken from the southern Gulf of St. Lawrence (4T) and the Breton Shelf (4Vn) (see Figure 26.2), found 90% of the parasites in the fillets and the remainder in the flesh surrounding the body cavity (belly flaps or napes; 6.8%), liver (0.7%), pyloric caeca (1.5%), and other viscera (1.2%). Distribution of the parasite varies with the length of the host: the larger the fish, the lower the percentage of *P. decipiens* in the fillets and the higher the percentage in the flaps. In the same study, no significant differences between infections in male or female fish were detected. In a recent study, McClelland et al. (1985) found that a significant majority of *P. decipiens* in the flesh of cod occurred in the nape and fillet in the left side of the body: nematodes in the left side outnumbered those in the right by 50%.

Figure 26.2
Sub-areas and Divisions of the Northwest Atlantic Fisheries Organization (NAFO) Convention Areas



The greatest infection levels of the less visible *Anisakis* spp. were in the liver (60.7%) and pyloric caeca (31.0%), with only low incidence in the fillets (1.1%) and flaps (1.2%), according to McClelland et al. (1983a).

Infection Rates

McClelland et al. (1983a), Templeman (1986) and others have noted that comparisons between recent and earlier studies on *P. decipiens* infections in commercial fish are extremely difficult for reasons centred on the following points:

- Research methods are not comparable. Some early studies used results from commercial candling procedures (described later in the Candling and Trimming section) which are less than half as efficient as those that include cutting the fillets into thin slices before candling, followed by systematic destruction of the slices. Even the latter method missed at least 13% of the *P. decipiens* and 68% of the *Anisakis*, as has been demonstrated by a peptic digestion experiment on fillets of cod (McClelland et al., 1983a).

- Units of expression are not comparable. Units used in recording worm infection are inconsistent and sometimes misleading. For example, average numbers of nematodes per fish, per fillet or per fillet weight do not take into account the skewed distribution (i.e., many fish are only lightly infected).

- Samples are not comparable. Different studies have involved different ages, weights or sexes of fish. In some cases, specific length ranges are mentioned; in others, the cod are only separated into "scrod", "market" or "steak". In addition, age/length relationships differ geographically, and hence data based on age of fish taken from different areas may not be from equivalent size classes of fish, and vice versa; time of year of sampling often differs among and within collections; and different populations of fish may have been sampled in the same location, but cannot be compared directly.

- Statistical methods used to test data may be inappropriate. Statistical studies on biological systems are based on many assumptions, some of which are violated because of the low numbers and natural variability in available data.

McClelland et al. (1983a, 1983b) compared intensities of infections of *P. decipiens* in commercial fish from the eastern coast of Canada. Given all the above limitations to analysis of present and past data, they still concluded that the variations in abundance of *P. decipiens* in relation to host length, season, year and geographical location were, for the most part, highly significant. Comparisons were made between and within the southern Gulf of St. Lawrence (4T) and the Breton Shelf (4Vn), and between and within Sable Island and Western banks (4W) and Banquereau (4Vs). (See Figure 26.2.) Their conclusions were as follows:

- The parasite was most numerous in inshore cod in both 4T and 4Vn.
- Mean counts of *P. decipiens* in cod from 4T and 4Vn offshore did not differ significantly, but counts of this nematode in 4Vn winter and summer samples were significantly different.
- Infections in 4W cod and flatfish were higher than in 4Vs cod and flatfish; parasite abundance increased with proximity to Sable Island.
- Infections of cod in 4T were similar to those reported 25 years ago.
- Cod and flatfish infections in 4V and 4W were much higher than they were 25 years ago.

These and other comparisons between early and recent studies are shown in Table 26.3.

Larval nematode infections in cod, American plaice, grey sole and yellowtail flounder were more recently reported for a broader area by McClelland et al. (1985). They concluded that *P. decipiens* was most abundant in fish from the southeastern Gulf of St. Lawrence (4T), Breton Shelf (4Vn), eastern Scotian Shelf (4Vs–4W), northeastern Gulf of Maine (4X) and lower Bay of Fundy (4X). *P. decipiens* had also become increasingly numerous in cod and flatfish from southeastern Newfoundland (3P–3O), the northern Gulf of St. Lawrence (4R–4S), and the southwestern Scotian Shelf (4X) (Figures 26.3 and 26.4).

By far the largest breeding colonies of grey seals in eastern Canada are located on Sable Island and in the southeastern Gulf, and each corresponds with a very high infection rate of cod with *P. decipiens* in the vicinity. The infection rate of cod with *P. decipiens* has risen greatly in the vicinity of Sable Island in relation to the 17-fold increase in grey seals (based

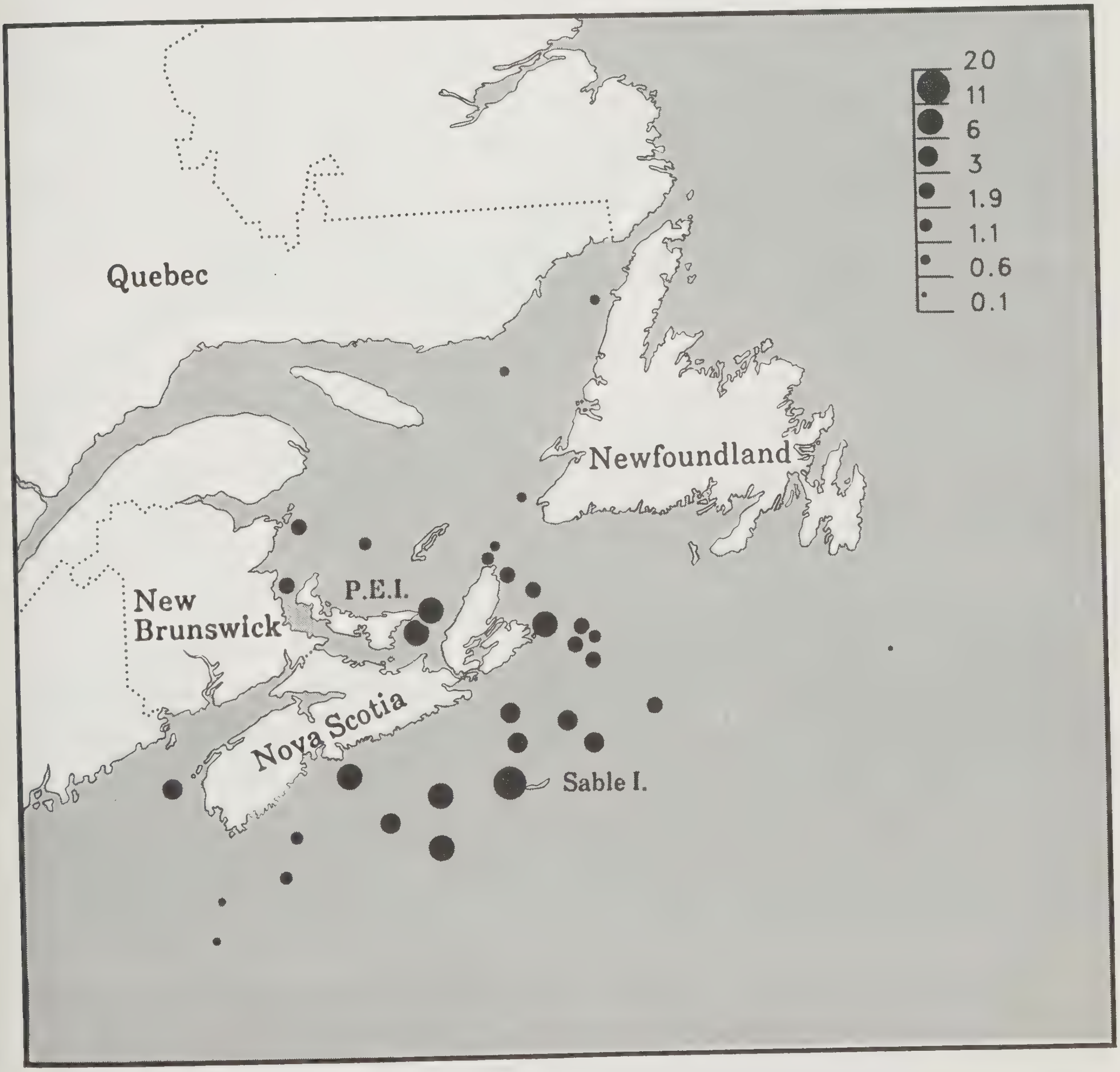
Table 26.3
Comparisons of *P. decipiens* Infections in Cod (or Plaice where Noted) between Early and Recent Studies

Location	Dates		Comparison of Infection Rates
	Early	Recent	
Sable Island/Banquereau	1950–52	1982	Much higher in 1982
Scotian Shelf (4Vs & 4N)	1946–56	1982	Much higher in 1982
Bradelle Bank–S Gulf of of St. Lawrence	1947–53	1981	Similar infection rates – smaller fish lower, larger fish higher, in 1981
Souris	n/a	1980–81	No early data; very high 1980–81
Cheticamp	1946–56	1980	Possibly lower in 1980
Shediac/ Point Escuminac	1957	1980	Lower in 1980
St. Paul's Island/Ingonish	1946–56	1980	No evidence of difference
S Gulf (4T) & Cape Breton (4Vn)	1950s	1980–81	No evidence of difference
SW Grand Bank (3O)	1947–53	1984	Much higher in 1984
N Gulf of St. Lawrence	1947–53	1984	Higher in 1984
S Scotian Shelf (4X)	1946–56	1983	Higher in 1983
Point Escuminac (plaice)	1949–53	1981	Much higher in 1981
NE Scotian Shelf (4VW) (plaice and witch flounder)	1947–53	1982	Higher in 1982
SW Grand Bank (3O); St. Pierre Bank (3P); N Scotian Shelf (4V) (plaice)	1947–53	1983–84	Higher in 1983–84
Bradelle Bank (plaice)	1947–53	1983–84	Lower in 1983–84
Miramichi, Cape Breton Shelf, Banquereau, Sable Island and Western banks (plaice)	1980–82	1983	Higher in 1983

Source: Templeman (1986) with comparisons of data in Templeman et al. (1957); Scott and Martin (1957, 1959); McClelland et al. (1983a, 1983b, 1985).

on pup counts; see Chapter 21) on this island between 1962 and 1984. It is not certain, however, whether the cod of the southern part of the Gulf of St. Lawrence, which were heavily infected with *P. decipiens* 30–40 years ago, have been more highly infected in recent years than they were formerly. This uncertainty results from the lack of equivalent earlier and later samples which are comparable for location, monthly date, method of examination, and fish size, as well as from difficulties relating to the comparable earlier and later numbers of grey and harbour seals, and the comparative role of harp seals. These questions were examined in detail in Templeman (1986).

Figure 26.3
Abundance of *P. decipiens* in Eastern Canadian Cod[a,b]



Source: Modified from McClelland et al. (1985).

a. Cod 51–70 cm in length, 1980–84.
b. Diameters of symbols are scaled according to mean nematode abundance per fish.

Studies in Scottish waters by Rae (1960, 1963), Wootten and Waddell (1974), Smith and Wootten (1979) and Wootten (1985) demonstrated the following:

- increases in incidence of infection by *P. decipiens* in cod of North Minch, South Minch and north of Scotland between 1958 and 1965 (1966–1967 for north of Scotland) and between 1971 and 1973;
- uncertain or no increases in Moray Firth and northern North Sea (between 1958–1961 and 1971–1973);
- a decrease between 1959–1970 and 1971–1972 in the Firth of Clyde.

Further examination of some of these areas in 1978–1979 showed a slight, but non-significant increase in the incidence of *P. decipiens* in smaller cod from the north coast of Scotland, and a decrease for North Minch. *Anisakis* infections for the north coast of Scotland had increased from 24% to 59% in the same period, but were reduced in North Minch (from 49% to 22%). Cod from the north coast of Scotland were examined again in 1981 and found to have a much lower incidence of *P. decipiens* infection (12.5%) than that from samples taken in 1978–1979 (34.1%) and in 1971–1973 (23.8%).

Host Specificity

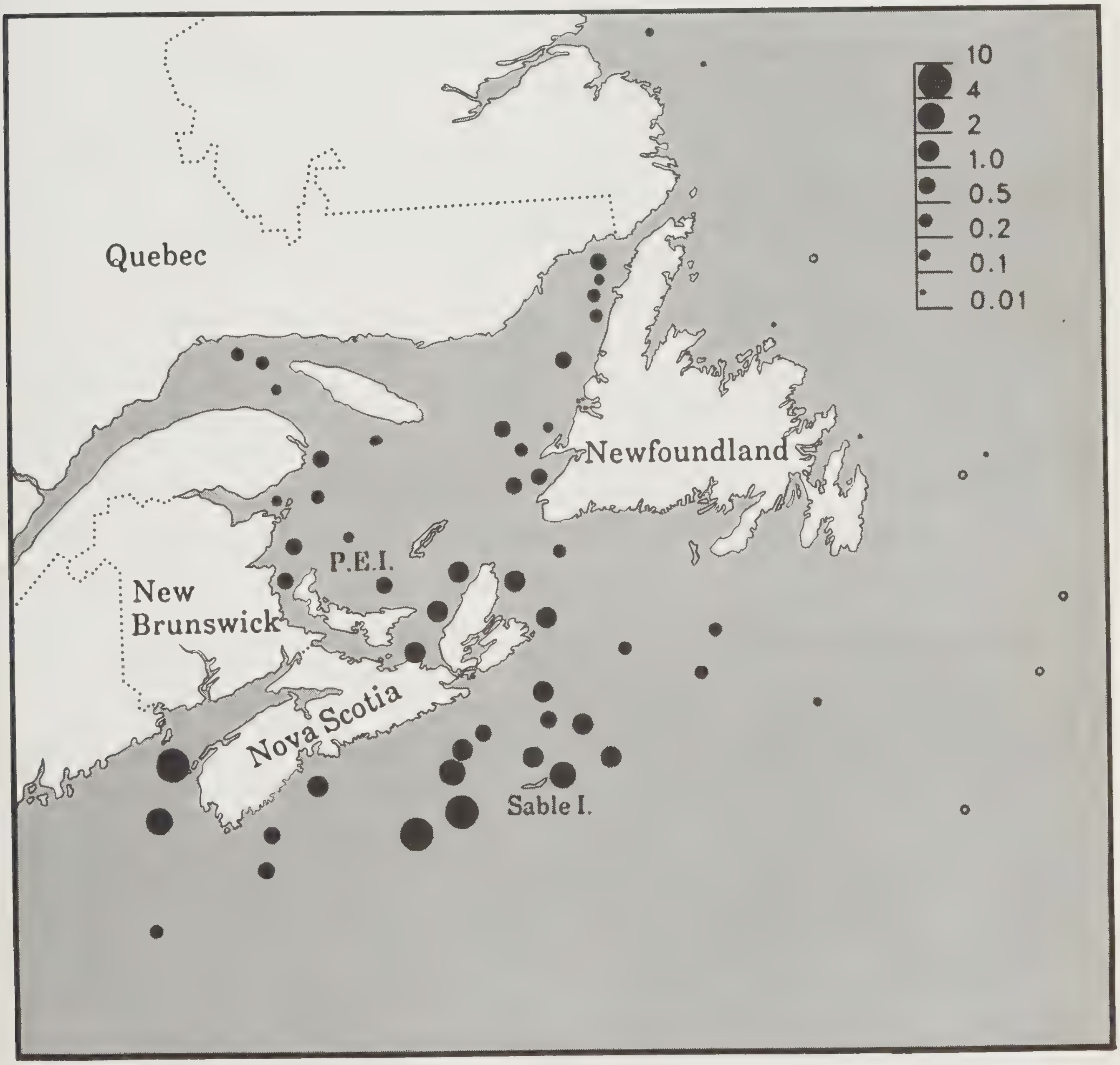
From the information given above, it can be seen that *P. decipiens* does not exclusively infect any one host in any of its life stages; that is, it is not host specific, especially in its younger stages. However, adult *P. decipiens* have not been reported from many marine mammals other than seals. Young (1972) found adult stages of the parasite in the stomach of a single sperm whale in South Denmark Strait, and Schmidt-Ries (1939) found that adult *P. decipiens* was the most important nematode in two common porpoises in the Baltic Sea. There is little doubt that seals along the eastern coast of Canada are by far the most important host for development of the parasite to the adult stage.

Relationships among *P. decipiens*, Fish and Seals

The preceding review of the life history of the parasite and its presence in seals and fish shows that it is reasonable to believe that the occurrence of parasites in fish and the associated problems of the fishing industry are

linked to the presence of seals on the fishing grounds. Before examining the evidence bearing on this statement, and the more specific question of the degree to which changes in seal abundance may result in changes to the numbers of parasites in fish, one complication should be noted. This complication is the existence of time lags in the system.

Figure 26.4
Abundance of *P. decipiens* in Fillets of American Plaice from Eastern Canada[a, b]



Source: Modified from McClelland et al. (1985)

a. Plaice 31–40 cm in length, 1983–1984.

b. Diameters of symbols are scaled according to mean nematode abundance per fish; open circles indicate zero abundance.

Given the time span for development of *P. decipiens* from an egg in the seal's faeces to a larva in fish flesh (Table 26.4), a minimum of about two months appears to be necessary between the production of eggs by an adult worm in an infected seal in the area and the presence of visible larvae in a fish. A maximum time from seal to fish cannot be as easily estimated, as much depends on the life span of the first and second intermediate hosts, but at least one and a half years could elapse between egg production and the appearance of infections in fish.

Table 26.4
Length of Time Required for Each Stage of Development of *P. decipiens*

Development Stage	Number of Days		
	Minimum	Mean	Maximum
Egg to hatch	8	N/A	52
Hatch to ingestion by first host	2	N/A	140
Growth in first host	7	15	35
Growth in second host to 2–3 mm	30	60	140
Growth in second host to 7–10 mm	N/A	90	N/A
Migration to muscle in fish host	N/A	2	N/A
Growth of larvae in fish	N/A	56	N/A
Growth and maturation in seals (until initial egg production)	15	N/A	25
Life span as adult	N/A	35	75

Source: McClelland et al. (1983a).
N/A = data not available.

After reaching the fish host, the larval worm in the flesh may remain infective to a seal for many years, perhaps for the life of the fish, although occasional encysted dead and disintegrating worms are found in older fish. A considerable amount of time could elapse, however, between infection of the fish and reinfection of the seal, and the complete cycle from seal back to seal (or fish back to fish) could take from several months to several years. Thus, changes in any one part of the system, such as reductions in seal populations, would not necessarily lead for some time to any noticeable effect in other parts of the system. General considerations of the life-cycle of *P. decipiens* lead to the conclusion that if the number of eggs of the nematode were greatly reduced, large reductions in its intensity of infection of fish would not be evident in the fishery until older, heavily infected members of the fish population and their food fishes were replaced by younger, presumably more lightly infected individuals. Thus, the length of time required for major changes to take place depends on growth rates of each species of fish, the age and size at which they are recruited to the fishery, the age to which they survive, and the age at which they became infected with *P. decipiens*.

These time lags are probably not important for interpreting past data when comparisons are being made over a period of decades, but they could be significant in considering future policy. The current infection rate in fish could represent the equilibrium parasite load corresponding to the seal population of some years ago. It must also be expected that if action is taken to control grey seals or other seal species, the results of that action will only become apparent slowly and gradually in the fish-processing plants.

Differences among Seal Species

The data presented in Table 26.1, together with the information on the numbers of seals given in Chapter 21, allow us to make rough estimates of the numbers of parasites in each seal species. Table 26.1 indicates that the parasite load for each species varies geographically and with time. For both grey and harbour seals the numbers of adult *P. decipiens* per seal at Sable Island increased (from 48 to 145+, and from 9 to 42 respectively) between the two periods 1949–1956 and 1983–1984. There are also indications that, for both of these species, the parasite load from 1949–1956 was higher in the seals from the coastal areas of Nova Scotia than it was in seals from Sable Island. Four harp seals taken at Port Hood, N.S. contained an average of more than 100 adult *P. decipiens*, while those taken near the Magdalen Islands averaged 0.03–5.0 nematodes per seal, and those caught near Labrador and along the north shore of the Gulf of St. Lawrence contained no adult and 0–0.2 adult *P. decipiens* respectively.

These geographical and temporal effects are confounded with the seasonal changes in infection rate, and few data are available. It is not possible at this time, therefore, to determine to what extent, if any, the infection rate in seals has increased, and to what extent it varies among areas. Given the changes that have occurred in the infection rates of fish and the differences among areas (and hence in the number of these nematodes that the individual seal will ingest in its food), it would be surprising if such differences between *P. decipiens* infections in seals did not exist.

For the purpose of comparison among species, it may be reasonable to take the figures from Table 26.1 and, for grey and harbour seals, to average the mean number of adult *P. decipiens* in each sample (i.e., 178 for grey and 17 for harbour seals). In the harp seal data, however, four individuals averaged 110 nematodes each, while all other samples ranged from zero to five *P. decipiens* per seal. The arithmetic mean (14.4 nematodes per seal) for these data could clearly be misleading. The omission of the four heavily infected seals results in an average of 0.8 *P. decipiens* per seal. The parasite load of harp seals from the Gulf of St. Lawrence may also have changed to a greater degree than that for other species of seal. The herring stock, which was a favoured food item of seals, and which contained very few *P. decipiens*, has declined greatly. Therefore, harp seals may have turned their attention to other, perhaps more heavily infected, fish. For the purpose of comparison, a figure of one *P. decipiens* per harp seal will be used.

Before combining the data for the number of *P. decipiens* per seal with the estimates of present-day seal populations from Chapter 21, two adjustments should be made to the data. The nematodes found in harbour seals are much smaller than those found in grey seals and have a correspondingly lower rate of egg production. Since the number of eggs produced is presumably the factor that is important to the effect on infection rates in fish, the numbers of adult *P. decipiens* per seal should be adjusted accordingly. On this basis, the mean number of *P. decipiens* found in harbour seals should be halved (i.e., to 8.5 nematodes per seal) to give a number equivalent to that for grey seals. The size of the adult *P. decipiens* found in harp seals has not been reported, but if the same relationship exists between nematode size and seal size, one adult *P. decipiens* in a harp seal might be equivalent to 0.75 adult *P. decipiens* in a grey seal.

The size of the harp seal population should also be adjusted because the parasite is only transmitted to and from those animals that enter the Gulf of St. Lawrence (an average of about one-third of the total harp seal population; Fisher, 1955; Sergeant, 1976; Winters, 1978). These animals

remain and carry adult *P. decipiens* in this vicinity for only a part of the year (perhaps one-third), and so the equivalent population size might be estimated at 220,000 harp seals.

The total parasite load for each of the three species of seals is calculated in Table 26.5.

Table 26.5
Estimates of the Total Numbers of Adult *P. decipiens* Found in Canadian Grey, Harbour and Harp Seal Populations

Seal		P. decipiens	
Species	No. (thousands)	Equivalent No. per Seal	Total No. (thousands)
Grey	70	178.0	12,460.0
Harbour	13	8.5	110.5
Harp	220	0.75	165.0

Despite the crude nature of these calculations, the dominant role of the grey seal – 98% of the total number of nematodes – is clear. Therefore the following section is couched entirely in terms of grey seals.

Relationship between Grey Seal Abundance and Infection Rate

The life history of *P. decipiens* (Figure 26.1) indicates that the presence of seals or other marine mammals is essential for the presence of the parasite. However, the number of eggs produced by a single adult female *P. decipiens* is so large that the presence of only a few female nematodes in a few seals could result in significant infections of fish stocks. Above a particular level, an increase in seal numbers might not materially alter the rate of infection of fish stocks. The beliefs that an increase in numbers of seals causes an increase in the infection rate of fish, and that a reduction of the seal population would be the best way to reduce the infection, are supported by two sets of correlations: those pertaining to space and to time.

Figures 26.3 and 26.4 show that the distributions of parasites in cod and plaice are similar, and both match the distribution of grey seals, with peak densities in the area near Sable Island, where a large breeding herd of grey seals is located; and secondary peaks in the southeastern Gulf of St. Lawrence, where there is another large breeding herd of grey seals. The trends of increasing abundance of *P. decipiens* infections in cod – from offshore to inshore in divisions 4T and 4Vn, and towards Sable Island in 4W and 4Vs – match the trends in seal abundance.

To some extent this picture may be blurred because of the movements of cod so that the observed infection of cod in one area is the result of the cod feeding on infected fish or invertebrate intermediate hosts in a different area. Those areas where cod populations are relatively sedentary may give a better estimate of the importance of local seal stocks. Some stocks of cod have a very high rate of infection by *P. decipiens* when there are only small colonies or concentrations of harbour and/or grey seals present (Scott and Martin, 1959; Scott and Black, 1960).

Similarly, a broad correlation between areas of high densities of grey seals and *P. decipiens* infections has been found in the eastern Atlantic. Studies have been carried out in the United Kingdom on the relationship of *P. decipiens* infections in cod to seal populations (Rae, 1960, 1963). Correlations have been observed between the coastal grey seal breeding colonies in northwest Scotland and the high incidence of *P. decipiens* (and *Anisakis* spp.) infections in cod (41%–55% coastally and 32% west of the coastal region). Grey seal colonies also exist close to other areas of high infection in the Shetlands (28% cod infected) and the Farne Islands off the east English coast (32% cod infected); intermediate and adjacent coastal areas through which seals from these colonies migrate showed intermediate incidence of infections in cod (13%–21%). Incidence of infection in the northern and southern North Sea were 4% and 0% respectively; these areas are progressively more distant from the main breeding colonies of grey seals.

The infection rate around the Faeroe Islands, where the number of seals is much higher than on Faeroe Bank (which is some distance to the west and is an area where seals are infrequently found), is 61% of cod, while on Faeroe Bank, only 1% of cod are infected (Platt, 1975).

A correlation also exists on a relatively fine scale. Bjørge (1985) presented information on the rate of infection of seals along the central coast of Norway. The areas where fish with high infections were found were always close to breeding colonies of seals.

Taking the geographic evidence as a whole, the conclusions seem fairly clear: the presence of some seals (or other marine mammals) is necessary for the presence of parasites, and the increasing numbers of seals are clearly related to the increasing infections in fish.

The evidence of the time-series data is less clear. Between 1962 and 1984 there was a 17-fold increase in the numbers of pups of grey seals on Sable Island. There has also been an apparent increase in *P. decipiens* larval infections in cod and flatfish fillets over the past 30 years in the area around Sable Island (Table 26.6), and a significant increase in cod and flatfish infections in relation to closeness to Sable Island (McClelland et al. 1983b, 1985; Figures 26.3 and 26.4).

Table 26.6
Number of *P. decipiens* per kg of Fillets in Cod Samples from Sable Island Bank and Banquereau

Fish Length (cm)	Early Samples[a]	Recent Samples[b]
35–50	0.88	6.12
51–70	0.74	8.39
≥71	0.09	10.68

Source: a. From Templeman et al. (1957).
b. From McClelland et al. (1983b).

It may be suggested that the change in the rates of infection of fish by *P. decipiens* may be simply a reflection of some changes in the natural environment which have happened to coincide with an increase in grey seal numbers. This possibility is somewhat strengthened by the apparent increase in the numbers of *P. decipiens* per seal observed in the Sable Island colony during the same period. Of the known environmental factors which may affect numbers of *P. decipiens* in seals and fish, water temperatures have, on the average, become somewhat colder since the 1930–1950 period and *P. decipiens* have become more plentiful in the interdependent cycle between seals and groundfish.

Even if the increases in seal numbers and in parasites do represent cause and effect, there are few data points for the intermediate years, and it is difficult to consider with any precision the relationship between intermediate numbers of *P. decipiens* in groundfish and intermediate numbers of seals.

In the eastern Atlantic, Wootten (1985) concluded, from his group's studies in Scottish waters, that the grey seal population had increased over the past 20 years around Scotland, but that the *P. decipiens* burden of the individual seal had remained much the same. Although the infection rate of larval *P. decipiens* apparently increased in fish between 1958 and 1973, no further increase was apparent between 1973 and 1979. The subject is discussed in considerable detail in Templeman (1986), where it was concluded that the small sample size and the lack of information on the relationship between distance from seal colonies and the location in time and space of the samples greatly reduced the value of the conclusions. In addition, the relative amounts of groundfish and pelagic species in the seals' food in earlier and later periods are unknown. Sand lance, a favourite food of the grey seal in Europe, has increased greatly in recent years off the Canadian and U.S. Atlantic coasts since its major predator, the cod, has been reduced in numbers. This increase in sand lance abundance may be also a factor in Europe, providing a change in the food of seals which might lead to fewer *P. decipiens* in the seals.

On the empirical evidence presented above, it can be stated that the evidence is in favour of the hypothesis that more seals will, on average, mean more parasites, but there are few data on the question of how much the parasite load in fish will change as a result of a given change in seal abundance to an intermediate level.

Human Health Hazards and Social Aspects of Nematode Infection

The public health aspects of human infection by the nematode *P. decipiens* were reviewed by Margolis (1977). That nematode and *Anisakis* spp. cause Anisakiasis, which produces severe epigastric pain, and may cause vomiting and other severe abdominal discomfort. Confirmed or presumed infections from *P. decipiens* had to that time been reported in 46 cases (of which 37 were in Japan, where raw fish is part of the normal diet, six from the United States, and one each from Canada, England and Greenland). All of these cases were linked to the consumption of raw, lightly salted or

marinated fish. Cooking at 70°C for seven minutes or freezing at –20°C for 24 hours is lethal to *P. decipiens* larvae in fish flesh. It appears that present methods of preparing fish for the table in Canada preclude the probability of high human infection rates with *P. decipiens*.

Human infections and even deaths from infection by *Anisakis* spp. have been reported from Holland in people who ate lightly salted raw herring (van Theil et al., 1960). This form of Anisakiasis is common in Japan also; over 1,200 cases were reported in the world between 1962 and 1977, mainly in Japan (Myers, 1970; Smith and Wootten, 1978).

The main public concern in North America with respect to nematode infections in fish flesh is the visibility and unsightliness of the parasite. Increased awareness of the public to health hazards from food and food products has probably contributed to an increase in complaints about the parasite. On the other hand, more people are becoming more adventurous in their eating habits, and the consumption of raw fish in Canada may be growing. Consideration of Japanese infection rates, however, leads to the conclusion that *P. decipiens* is probably not a major health hazard, especially when compared to *Anisakis* spp.

Economic Implications of *P. decipiens*

The occurrence of *P. decipiens* in fish flesh adds to the costs for the fishing industry, including the costs for candling the fish fillets in order to remove the parasites, trimming and discarding badly infected portions of the fillets, reduced quality of the fish products resulting from the presence of parasites, and the abandonment of some fishing areas because of their very high infection rates.

Candling and Trimming

Candling involves a visual examination of the fillet for the presence of nematodes. A light source is placed under a frosted glass surface on which the fillet is placed, and the parasites are removed individually with the tip of a knife. In large, thick, potentially high-quality fillets that are heavily infected with *P. decipiens*, it is impossible to produce an acceptably nematode-free fillet without slicing the fillet thin, which downgrades the final product. Candling also removes bones, scales, blood clots, *Anisakis* spp. and other parasites, and consequently much of the fish would have to be candled even

if there were no *P. decipiens* present (George, 1986). Thus the cost of candling cannot be attributed to *P. decipiens* alone.

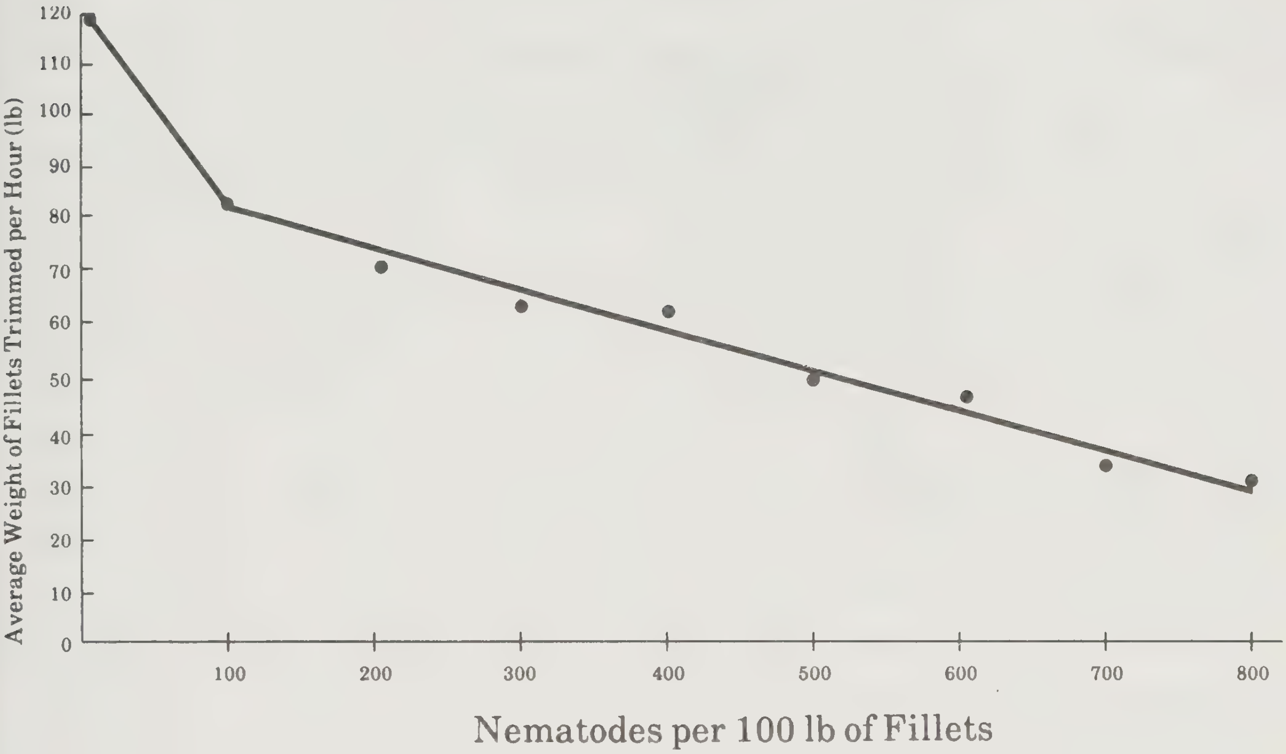
When trimming fillets containing significant numbers of nematodes, processors often cut away the napes (belly flaps) because of heavy concentrations of the parasites. In the past, the napes of cod were routinely discarded, but increases in the price of fish in recent years have made it profitable to retain part of the nape as part of the fillet. The Task Force on Seal Borne Parasites (Canada, DFO, 1983) estimated that removal of highly infected napes reduced the fillet yield by about 10%, or 3.5% of round weight, but reduced the value of the fillet by an amount somewhat less.

Candling does not remove all of the nematodes from fish fillets. At input levels of 500–800 nematodes per 100 pounds of fillets, candling removed 90%–95% of the nematodes at a N.S. plant (O'Neil, 1985), a considerably higher level than the 75%–85% reported by the Task Force. The Department of Fisheries and Oceans has an unofficial tolerance limit of 33 nematodes per 100 pounds of finished product, above which the fish is declared unwholesome and must be downgraded to meal or salted (O'Neil, 1985). At a 95% removal rate, all fish with more than 660 nematodes per 100 pounds of uncandled fillets would be processed as meal or salted.

When dealing with market cod containing large numbers of parasites, a bottleneck occurs in the trimming and candling area that severely affects the plant capacity and increases the costs of the whole throughput operation. Figure 26.5 shows the decrease in throughput with increasing parasite load for a N.S. processing plant (O'Neil, 1985).

Data from Frick (1956) for four groups of filleting plants in the Maritimes in 1954–1955 (Table 26.7), demonstrate that the higher the ratio of candlers to filleters, the lower the percentage of nematodes remaining in fillets. The efficiency of nematode removal at these plants, however, was much lower than that reported by O'Neil (1985). In southern and western Nova Scotia at that time candling in many plants was only intermittent, and a high percentage of nematodes (48%) were not removed. In eastern mainland Nova Scotia, the candler/filleter ratio of 0.33 appeared adequate, resulting in an acceptable level of unremoved nematodes (25/100 lb fillets); it is likely however, that the plants in this area received some cod from the Grand Bank that contained relatively few nematodes and required little candling. In the Gulf of St. Lawrence, the infection density and the candler/filleter ratio were the highest, and the percentage of nematodes remaining in fillets was the lowest (26%); but the numbers of nematodes remaining were the highest (60 per 100 lb).

Figure 26.5
Through-put of a Trimmer at a Nova Scotian Processing Plant



Source: O'Neil (1985).

Table 26.8 summarizes information supplied by one of Nova Scotia's largest fish-processing plants on the costs of candling cod fillets relative to the numbers of nematodes present (O'Neil, 1985). The direct labour costs are given from the time the fish are unloaded until the finished product is frozen (including filleting, candling, trimming and packing); they do not include the costs of indirect labour, such as supervision and administration, or the application of overheads. The direct labour costs increased from approximately \$27 per 100 pounds of fillets, at a level of zero infection, to approximately \$59 per 100 pounds, at a level of 800 nematodes per 100 pounds. The cod which had the lowest level of infection were caught near Labrador (division 2J); those cod which had higher levels of infection were caught near Newfoundland (divisions 3K, 3L, 3O, 3Ps); and those which had the very high levels were caught on the northern part of the Scotian Shelf (divisions 4Vn, 4Vs, 4W) (O'Neil, 1985). These labour costs are for the removal of all nematode parasites, as it is not possible to provide separate costs for *P. decipiens* alone.

Table 26.7
Numbers of Candlers and Filleters for Cod, and the Nematode Content of Fillets Before and After Candling

	E Cape Breton	E Mainland Nova Scotia	S & W Nova Scotia	P.E.I. & N New Brunswick	All Plants
1955					
No. plants surveyed	7	9	9	9	34
No. filleters	171	251	92	142	656
Production of fillets/ filleter/8-h day	770	800	780	760	780
Ratio of candlers: filleters (cod)	0.71	0.33	0.25	1.41	0.65
Finished product wt. (cod fillets, blocks & sticks) in 1954 (× 1000 lb)	6,267	17,540	3,715	5,627	33,149
1954/1955					
No. plants surveyed	3	3	3	8	17
No. nematodes/100 lb:					
Before candling	120	94	88	233	129
After candling	41	25	42	60	44
Nematodes remaining (%)	34	27	48	26	34

Source: Frick (1956).

It has been argued that the removal of nematode parasites creates jobs in Atlantic Canada (Earle, 1985; McDermott, 1985). As Chapman (1985) pointed out, however, in his testimony for the Fisheries Association of Newfoundland and Labrador Ltd., the cost of removing nematodes from fish comes directly from the gross margin earned by processors. To keep the product competitive with export markets, processors have been dropping their gross margins, and some have been pushed close to, or into, bank-

ruptcy; consequently, prices paid to fishermen have decreased. The cost of nematode removal thus results in lower prices to fishermen.

Table 26.8
Direct Labour Costs for Cod Fillet Production at a Nova Scotia Fish Processing Plant, January–June 1985[a]

Nematodes per 100 lb fillets[b]	Fillets Candled and Trimmed (1000 lb)	Direct Labour Costs ($ per 100 lb fillets)	Costs in Addition to Base Costs at Zero Nematodes ($)	Savings per 100 lb Fillets ($)[c]
800	30	58.9	32.2	–
700	33	54.8	28.1	4.1
600	44	45.6	18.9	9.2
500	50	42.1	15.4	3.5
400	60	37.7	11.0	4.4
300	63	36.3	9.6	1.4
200	70	34.3	7.6	2.0
100	80	31.9	5.2	2.4
0	115	26.7	0.0	5.2

Source: Modified from O'Neil (1985).

a. For filleting, candling, trimming and packing (from unloading to freezing).
b. Values are rounded to the nearest hundred pounds.
c. Calculated as the difference between the dollar values for the upper and next-lower nematode levels.

Other Costs

In addition to the direct labour cost of removal of parasites and the lost yield caused by discarding heavily infected napes, there are several other costs to the fishing industry resulting from the presence of the parasites. There are several ways in which the quality of the fish products may be downgraded as a consequence of the nematodes. Thin slicing of heavily infected fillets for candling results in a less desirable product, and the cutting and the lengthened processing time cause a deterioration in the quality of the fish flesh. Fillets with nematodes remaining in them are sold at lower values than fillets that are virtually nematode free.

Some fish are diverted to lower value packs because adequate removal of parasites cannot be accomplished without the incremental costs exceeding incremental value. Fish may have to be sold in the cheaper block form rather than in the more valuable fillet form, or if the infection levels are too high, the fish may have to be salted or processed as meal. In the Canadian fisheries statistics for 1982, exports of frozen cod fillets were valued at $35 per 100 pounds more than frozen cod blocks (Canada, DFO, 1984). Factors other than the presence of parasites, such as the size and quality of the fillets and the market requirements for fillets or blocks, also enter into the decision concerning which form to produce. Production of blocks may incur considerably more labour costs than production of fillets (Frick, 1956).

According to the Seafood Producers Association of Nova Scotia (1985), no comprehensive study had been made to determine downgrading losses caused by nematodes, but these costs are significant, as are sales lost because of consumer fears. Commercial buyers may also downgrade prices or refuse shipments, ostensibly because of nematodes in the fish; they may, however, be using the presence of parasites as a bargaining lever, in order to purchase the product at a lower price (Canada, DFO, 1983). The result is a lower market value for the fish.

Several additional costs may be associated with candling and trimming. The Task Force on Seal Borne Parasites stated that there were costs attributable to the capital outlay for candling tables and the potential expenses of plant modification to accommodate the candling process, as well as additional costs for training and supervision (Canada, DFO, 1983). George (1986) included an overhead cost to cover variable expenses such as additional workers' wages for processing heavily infected fish; but he discarded the capital costs of candling tables and plant modifications because the annual costs of the candling tables were insignificant, because the candling process would be needed even in the absence of *P. decipiens*, and because fish processing is not a capital-intensive operation.

There are some areas of eastern Canada where *P. decipiens* is so plentiful in fish flesh that it is unprofitable to use the fish commercially for fillets or blocks. In essence, this reduces the area available for commercial fishing. On the Scotian Shelf, for example, cod in the 46–50 centimetre range, caught off the East Bar of Sable Island Bank, contained 1,900 *P. decipiens* per 100 pounds of fillets (McClelland et al., 1983b), and plaice from the Western Bank contained 4,570 *P. decipiens* per 100 pounds of fillets (McClelland et al., 1985). These parasite loads are too high for the fish to be sold as fresh or frozen; instead it must be produced as low-priced saltfish or fishmeal. With the increasing numbers of grey seals and the increasing

prevalence of *P. decipiens*, it seems likely that the areas where commercial fishing is unprofitable will be extended.

Total Cost of *P. decipiens* to the Fishing Industry

Atlantic Canada

The Task Force on Seal Borne Parasites (Canada, DFO, 1983) estimated the 1982 cost to the Atlantic fishery for the removal of parasites from cod and the discarding of infected napes of cod to be $29,273,000. Of this total amount, approximately $26,000,000 was attributed to *P. decipiens* and the remainder to the presence of *Anisakis* spp. The incremental labour costs for candling and trimming were estimated at $14,249,000 (Table 26.9). The loss of yield from the discarding of heavily infected napes of cod was estimated to be $15,024,000 (Table 26.10). This calculation was based on assigning the napes the approximate weighted average market price for Canadian cod products in 1982 (Canada, DFO, 1983), which may have resulted in the napes having slightly too high a value.

In a more recent study made for the Royal Commission, George (1986) estimated the costs and losses of revenue incurred during the processing of cod, flatfish and other groundfish from Newfoundland and Nova Scotia as a result of the presence of *P. decipiens* in the fish. His estimate is summarized in Table 26.11, and his detailed calculation is presented in Appendix 26.1. The study is restricted to the costs that can be attributed to *P. decipiens*; it does not include the costs derived from other parasites or other reasons for candling. Included in the total estimate for cod are the cost of candling fillets, and the losses of revenue from the downgrading of fillets and the discarding of napes. For flatfish and other groundfish, the estimate covers the cost of candling.

The total costs attributable to the presence of *P. decipiens* in cod and flatfish from Newfoundland and Nova Scotia were estimated at $26.6 million for 1984 (George, 1986). Costs for Newfoundland cod were estimated at $12.4 million, and costs for Nova Scotia cod and flatfish were estimated at $14.2 million.

The study did not include estimates for New Brunswick, Prince Edward Island or Quebec. Most of the cod and flatfish landed by these provinces inhabit heavily parasitized areas of the Gulf of St. Lawrence; however, the catches of cod and flatfish for these provinces are low relative to those of

Table 26.9
Labour Costs for Candling and Related Trimming Attributable to the Presence of Nematode Parasites in Cod, 1982

Nematode Parasite	Location (NAFO Div.)	Approx. No. of Parasites per 100 lb Fin. Prod.	Finished Product Weight (lb)[a]	Cost of Candling and Labour per 100 lb Fin. Prod.	Total Candling and Trimming Costs
P. decipiens	4VW	250	54,127,000	9.40	$5,088,000
P. decipiens	4RST, 3Pn	150	112,474,000	7.20	8,098,000
P. decipiens	3Ps	40	23,274,000	3.50	815,000
Anisakis	2J, 3KL	22	70,958,000	0,35[b]	248,000
Total labour costs resulting from presence of nematodes					$14,249,000

Source: Adapted from Canada, DFO (1983).

a. Weight after filleting, but before trimming.
b. Incremental cost per 100 lb of napes.

Newfoundland and Nova Scotia. On the assumption that circumstances in New Brunswick, Prince Edward Island and Quebec approximated those in Nova Scotia, it is estimated that the costs attributable to *P. decipiens* for those three provinces would be about $3.1 million, for a total annual cost of $30 million for eastern Canada (Table 26.11).

Some costs have not been included in the estimate prepared by George (1986). They include: the downgrading of heavily infected cod for meal or salting, losses resulting from non-fishing of heavily infected areas, and the costs of a reduction in plant capacity and fillet production because of the plant capacity devoted to trimming and candling. It is not possible to estimate these additional costs.

Other information on costs in Atlantic Canada was provided to the Royal Commission by: the Nova Scotia Department of Fisheries (1985), which estimated that removal of nematodes from cod and plaice added close to $0.20 per pound (1984 dollars) to the processing costs (based on a newspaper interview with a fish processor); by the Fisheries Council of Canada

Table 26.10
Costs of Discarding Napes of Cod Heavily Infected with Nematode Parasites, 1982

Nematode Parasite	Location	NAFO Div.	Napes Discarded (%)	Round Weight (lb)	Cost of Discarding Napes[a]
P. decipiens	NE Scotian Shelf	4VW	40	164,022,000	$3,743,000
P. decipiens	Gulf St. Lawrence, St. Pierre Bank, S Coast Nfld. and adjacent bank	4RST 3P	35	411,359,000	8,214,000
Anisakis	Labrador Shelf, NE Nfld. Shelf, East Coast Nfld. and N Grand Bank	2J 3KL	25	215,024,000	3,067,000
Total for lost yield					$15,024,000

Source: Adapted from Canada, DFO (1983).

a. Based on 3.5% loss of round weight yield at an average price of $1.63/lb.

(1985), which estimated that candling can add up to $0.10 per pound to processing costs; and by the Seafood Producers Association of Nova Scotia (1985), which estimated that the reduced yield and labour costs associated with nematode removal from cod had risen to between $40 and $50 million by 1984.

The magnitude of the problem caused by *P. decipiens* to the Canadian Atlantic fishery has been increasing over the years as the parasite has become more prevalent. The Task Force on Seal Borne Parasites stated that the occurrence of parasites in flatfish was restricted geographically, but expressed concern that the problem in flatfish would increase and become a generalized east-coast problem (Canada, DFO, 1983). The Seafood Producers Association of Nova Scotia stated that they foresee considerable risk of increased costs if seal herds increase still further, and if the recent trends in

Table 26.11
Costs and Losses of Revenue ($million) to Fish Processors in Eastern Canada due to the Presence of *P. decipiens* in Fish, 1984

	Newfoundland	Nova Scotia	Total
Cod: candling fillets	8.46	6.56	15.02
candling napes	0.72	0.33	1.05
downgrading fillets	1.38	3.08	4.46
discarding napes	0.22	0.94	1.16
Flatfish: candling fillets	a	0.61	0.61
Other groundfish: candling fillets	1.40	2.40	3.80
Claims due to excess *P. decipiens*	0.10	0.10	0.20
Training costs	0.15	0.15	0.30
Total costs and losses in Newfoundland and Nova Scotia	12.43	14.17	26.60
Total costs and losses estimated for New Brunswick, Prince Edward Island and Quebec: cod, flatfish and other groundfish			3.09
Total costs and losses in eastern Canada			29.69

Source: Adapted from George (1986).

a. Flatfish landed in Newfoundland are not significantly affected by *P. decipiens.*

parasite prevalence and geographical expansion of both seals and *P. decipiens* infections continue.

Pacific Coast

This chapter has concentrated on the costs of *P. decipiens* to the Canadian Atlantic fishery because of the magnitude of that problem. Information on the problem on the Pacific coast is available from the Prince Rupert Fishermen's Cooperative Association (PRFCA, 1985). Candling of fillets of cod, halibut, rockfish, ocean perch, sablefish and other species of fish in order to remove parasites (mainly *P. decipiens*) costs the Cooperative \$100,000–\$200,000 annually in labour costs and reduced yield. At times, fish cannot be marketed because of the nematodes. Whole deliveries of groundfish have been rejected for market and have had to be reduced to fishmeal. Major losses have not been incurred in the processing plants, but they have occurred in the market place through loss of customers and decrease in product value. The estimated total loss to the B.C. fishing industry from parasites is potentially in excess of \$1 million according to PRFCA (1985).

Northeast Atlantic

The ICES (1979) working group on interactions between grey seal populations and fish species noted that high levels of *P. decipiens* in cod added a great economic burden to the fishing industry in Scotland and elsewhere. The Royal Norwegian Ministry of Fisheries (Øritsland, 1985) stated that the most severe seal-related problems and economic losses to fishermen and processors in Norway were caused by the presence of *P. decipiens* in fish.

Options for Dealing with *P. decipiens* Infections

The increasing prevalence of *P. decipiens* in fish flesh is clearly causing a major problem for the Canadian Atlantic fishing industry, and it would be highly desirable if the numbers of *P. decipiens* could be reduced. Several options have been suggested to reduce the infection rates of *P. decipiens* and/or to combat the problem through changing fishing practices or fish-processing methods.

Reduction of Seal Populations

Reduction of seal populations is the most frequently suggested option to reduce *P. decipiens* infections in commercial fish, given the assumption that more seals mean more nematodes and vice versa. The chief target for suggested culling is the grey seal, because it is the main final host for *P. decipiens*, and because its numbers have been increasing dramatically in the last 20 years.

A limitation to seal culling is that small numbers of seals are capable of maintaining high incidences of *P. decipiens* in cod, at least in some circumstances. The cause appears to be the wide-ranging habits and high parasite loads of some seals, and the high fecundity of adult female *P. decipiens* (Scott and Martin, 1959; McClelland, 1980; Beck, 1983). In addition, migrating stocks of cod may acquire their parasite loads in distant areas (Scott and Martin, 1959; Platt, 1975). A reduction in seal numbers would probably need to be of a considerable size before any effects could be observed in the numbers of *P. decipiens* in fish.

Another major uncertainty is the relative contribution of harp seals to infections of commercial fish by *P. decipiens*, as compared to the contribution by grey seals, the usual target suggested for culling.

A scientific working group of the International Council for the Exploration of the Sea (ICES, 1981) concluded, with reference to grey seals in the United Kingdom, that it was impossible to say whether levels of seal-borne infection by *P. decipiens* would show a significant reduction after a reduction in seal numbers, because of the high fecundity of the parasite and the existence of alternate hosts. The Committee on Seals and Sealing (COSS, 1985), while recognizing in its brief that the grey seal appears to play a significant role in transmission of *P. decipiens* to commercial fish stocks, believed that it was not clear whether the parasite would find a substitute host if action were taken to reduce drastically the number of grey seals. COSS called for more work on methods of controlling the transmission of parasites and of removal of parasites from fish fillets, rather than assuming that the problem would be solved by eliminating the grey seal.

May (1985), in testimony for the Department of Fisheries and Oceans, suggested that "the only way to find the answer would be to do it" (i.e., control grey seals). Earle (1985) suggested that "before the adoption of such drastic management schemes, experiments should be conducted on a limited scale to determine the effects that altering seal population levels would have, both on the incidence of anisakids in commercial fish, and on the

productivity of the seal population." These experiments could include long-term monitoring of the incidence of *P. decipiens* in seal and fish populations in areas where seals have and have not been reduced, along with life-history studies on the seals in both sets of areas.

Control through Eggs, Larvae or Invertebrate Hosts

Most of the detailed knowledge of *P. decipiens* infections in intermediate hosts has been gained from laboratory experiments (McClelland, 1982; McClelland et al., 1983a) in which high infection rates were induced in copepods (from one to 39 nematodes per copepod with averages as high as 18) and an amphipod species (100% infection with an average of 60 nematodes per amphipod). *P. decipiens* is found much less frequently, however, in natural samples taken at sea. A sample of 2,000 amphipods taken from the sea produced only three that were infected, each with only a single *P. decipiens* larva (McClelland, 1982; McClelland et al., 1983a). In the Bras d'Or Lakes, 8,000 mysids were found to contain 110 nematodes, of which only one was definitely identified as *P. decipiens* (Scott and Black, 1960). In an area near a large Norwegian grey seal colony, Bjørge (1979) found one *P. decipiens* larva in 84 specimens of the isopod *Idothea neglecta* that were taken in good condition from cod stomachs. The larval stages of *P. decipiens* are thus comparatively scarce in their invertebrate intermediate hosts under natural conditions and are unlikely to be harming these hosts through being too numerous in them.

Chemical or physical control of these small invertebrate hosts is impractical, because of their vast numbers and wide distribution, and because *P. decipiens* does not appear to be limited to one or a few such species. Chemical or physical control would also adversely affect other organisms, including commercial crabs, shrimps and lobsters, and the food species of many fish.

It might be more practical to conduct research into methods for destroying possible concentrations of eggs and larvae of *P. decipiens* attached to the bottom substrate near seal colonies, but it would be necessary first to determine whether such concentrations exist.

Control through Small-Fish Hosts

Smelt, which spend most of their marine life in sheltered coastal locations that are often near harbour seal colonies, are heavily infected with

P. decipiens (Scott, 1954; Templeman et al., 1957). Further research on these and other small fish that may act as intermediate hosts could be carried out near seal colonies and elsewhere. Depending on the results, it might be possible to fish these small fish intensively in order to reduce the population of *P. decipiens*. Such a practice would probably be effective only for localized infections, however, and it could have unwanted effects on larger fish or other species that feed on these small fish.

Alteration of Fishing Practices

It has been suggested that in European waters, fishing be directed toward larger and older fish because larger cod have fewer nematodes per unit weight of fillet (Young, 1972). Although the same is true of American plaice in Canadian waters, cod fillets tend to contain increasing numbers of *P. decipiens* larvae per unit weight as their size increases (McClelland et al., 1983a, 1983b, 1985). Thus there is an advantage in taking smaller cod in areas of high infection rates in Canadian waters. It is also much easier to detect and remove the parasites from smaller cod fillets. The disadvantages of doing so include: the capture of small, heavily infected plaice in the small-mesh fishing gear required to take smaller cod; the reduced desirability of small fish to the fishing industry as a source for fillets or salt fish; the reduced total biomass available for commercial fishing; and the reduced recruitment to the spawning population of fish.

Alteration of Fish-Processing Methods

Routine removal of the napes from fish during processing would eliminate some of *P. decipiens* and the majority of the flesh-dwelling *Anisakis*. Better candling techniques, including development of sophisticated ultrasonic or laser detection technology to detect which fish contain nematodes would reduce the parasites in the final product (McClelland et al., 1983a), and reduce costs by enabling processors to concentrate on infected fish. The Task Force on Seal Borne Parasites (Canada, DFO, 1983) described a German technique that combines ultrasound with computer video equipment which can detect, locate and remove nematodes automatically. The Task Force suggested that modern, modified or new technologies be investigated with respect to their effectiveness and costs in removing nematode infections from commercial fish. However, these mechanized methods may be too expensive for small plants to undertake; and even with the best methods the costs will remain high.

Discussion

It is clear from the foregoing information that the presence of nematode parasites in the flesh of fish adds appreciably to the costs of fish processing , and reduces the value of the product. The total cost for Atlantic Canada is at least $30 million annually. It is also clear that there is a high positive association, in both space and time, between high densities of seals, especially grey seals, and high levels of *P. decipiens* infection in fish. From knowledge of the life history of the parasite, it appears highly probable that if there were no seals, there would be so few *P. decipiens* in fish flesh that the economic impact would be close to zero.

Reducing seal populations to a level so low that extinction is a possibility is not a management option that would be acceptable to the Canadian people as a whole, nor is it one that any representative of fishing interests appearing before the Royal Commission has suggested as being desirable. The options open for managing seal numbers are, therefore, either to do nothing and allow seal stocks to increase to levels governed by natural conditions, plus whatever hunting that that course of action might permit, or that might be economically viable; or to establish a level of cull aimed at bringing the seal population to, and maintaining it at, some level below the natural equilibrium.

Grey seals, the main final host, are now increasing rapidly, despite a cull on some of the colonies. (See Chapter 21.) There is no reliable information on the level of abundance that they would reach if there were no cull, though it could be considerably higher than at present.

The effect of such an increase in grey seals on the prevalence of parasites and on their economic impact is equally uncertain. It is conceivable, given the uncertainty about the dynamics of *P. decipiens*, that the degree of infection in certain areas is already at, or approaching, limits set by natural factors other than seals, so that the effect will be minor. It is more likely, however, that higher numbers of seals will result in a considerable increase in infection rate and in related economic loss. It is even possible that the rate of infection, for increasingly larger fishing areas in eastern Canada, would rise to such a level that the costs of processing would be so high and the value of the ultimate yield so low, that it would no longer be worthwhile for fish companies to buy the principal species of groundfish from these areas for processing fresh.

There is no way, at present, to distinguish among this range of possibilities. What can be said, though, is that to allow the stocks of grey and

other seals to increase up to an unknown biological limit would pose an additional risk, unquantifiable but probably not negligible, to the fishing industry in a large part of eastern Canada.

If the alternative policy of carrying out a cull is adopted, the choice of cull level will depend on the relationships between the cull and the number of seals in the stock, and between the number of seals and the economic losses caused by parasites.

The first factor is discussed in Chapter 29; the second needs to be examined in two stages: the relationships between the number of seals and the degree of infection, and between the degree of infection and the economic loss. Neither relationship is likely to be directly proportional.

The information available on the relationship between parasite infection rates and economic loss (Tables 26.8 and 26.9) shows that it is desirable to reduce the numbers of parasites at the higher levels of parasite density. Additional costs, including downgrading, loss of plant production, market acceptability and loss of fishing areas are greatest at the higher nematode levels.

The relationship between infection rate and numbers of seals is far less clear. The dynamics of a parasite with several intermediate hosts are complicated, and it is unlikely that the frequency of parasites in one host (e.g., cod) will be related in any simple way to the abundance of one of the other hosts (e.g., seals). The abundance and variety of the intermediate hosts should allow differences in various areas between the infection rates of *P. decipiens* in fish and the numbers of seals. Greatly fluctuating populations of pelagic fish such as herring and capelin that are not infected with *P. decipiens*, may replace, to a greater or lesser extent, groundfish infected with this nematode in the food of the seal, thus leading to fewer *P. decipiens* in the seal's stomach. Depending on the relative amounts of pelagic fish and groundfish eaten, *P. decipiens* may be displaced or crowded out of the seal's stomach by other nematodes, as suggested by McClelland et al. (1985). Moreover, depending on the number of adult *P. decipiens* in seals, there may be differences in the number of the larvae of this nematode in groundfish and vice versa.

The factors that determine the frequency of occurrence of the parasite in the flesh of fish, and how this frequency might be related to the abundance of seals are not clear. There is a considerable literature on the dynamics of the host-parasite system (Anderson and May, 1982; Anderson, 1980). The literature deals mostly with situations where the interest is in the well-

being of the final host – humans or their domestic animals – and in methods of control aimed at reducing an intermediate host, for example, the malaria mosquito or the snail that carries the bilharzia parasite, to as close to extinction as possible. The direct relevance of the available literature to the problem of controlling infection in an intermediate host by some control, but not too drastic a control, of the final host is therefore limited.

The available information does, however, provide some insight into the patterns likely to be occurring in the *P. decipiens*–crustacean–fish–seal systems. First, the relationships, for example, between rate of infection in fish and seal abundance, are unlikely to be simple. A proportional relationship is possible, but it is equally likely that changes in seal numbers over the moderate range likely to be acceptable in practice may have very little effect on infection.

Secondly, the host that is likely to have the greatest effect on the dynamics of the system as a whole is the one in which the parasite spends the longest time (Anderson, 1985), that is the fish. If this supposition is true, it suggests that measures to modify the abundance and age structure of populations of cod and other fish may be more effective in controlling infection than the culling of seals. In particular it might be desirable, in areas where infection is a serious economic problem, to consider fishery-management plans which are aimed at a low density of predominantly small fish so that the build-up of parasites in fish, and their transmission through fish to seals and to the next generation of parasites, are reduced. This type of manipulation would be directly opposed to current fishery-management objectives, and it would not necessarily be an effective alternative. For example, *P. decipiens* can become sexually differentiated in its amphipod host and may reach the stage in the amphipod where it may be directly infective to seals, completing its life-cycle without a fish host (McClelland et al., 1983a). The relative importance of this pathway is, however, unknown.

There is far too little information available on these subjects, and it is premature to suggest any modification to existing fishery management plans. A brief examination of the theory of host-parasite dynamics does suggest however, that the possibility exists of limiting parasite damage by other means than that of controlling seals, even though, on currently available information, the latter is the most promising.

A priority must be to conduct more research on the intermediate hosts. This should include further studies on infections of intermediate hosts and the distribution of parasite larvae on the bottom substrate. It is also necessary to collect more information on the degree of infection in fish as

related to the age and size of fish, since age can be a significant factor (e.g., Grenfell and Anderson, in press). This research needs to be linked to theoretical studies and modelling of cod–seal–parasite dynamics. Since Iceland, Norway and the United Kingdom are facing the same problem, and the United Kingdom, at least, is considering increased research, it would be highly desirable to integrate future Canadian research on this topic with research on the other side of the Atlantic. This would be particularly desirable and cost effective for the theoretical studies, which should, if possible, be based on existing theoretical host-parasite studies.

Despite these uncertainties, and until further studies are carried out, it is still desirable to consider to what extent the degree of infection is likely to change with changes in seal abundance, either through natural increases or through reductions as a result of a cull. A number of relationships between seal abundance and infection rate in fish are possible. Though a directly proportional relationship cannot be rejected, the most plausible relationship would be a family of S-shaped curves, with infection rate increasing relatively slowly with increasing seal numbers except over a critical range. This curve could have a wide critical range and some change in infection rate with increasing seal abundance, both above and below it. The changes might, on the other hand, be much more abrupt, and most changes in the equilibrium infection rate might occur over a narrow range of seal abundance. In the latter case reductions in seal abundance would have little effect on infection rates, and hence on losses, unless these reductions brought the abundance of seals from above to below the critical level.

In eastern Canada, many of the main groundfish species infected by *P. decipiens* can be identified as stocks. The mature fish are distinct at spawning time, but during feeding seasons and when immature, they overlap somewhat with adjacent stocks of the same species. Grey and harbour seals, too, are more or less localized, with less than complete mixing between areas. These differences are reflected in the different levels of infection and hence different costs of infection in different areas. The effects of changing the overall abundance of seals might therefore be expected to be different in different areas. In some areas, the local density of seals may be near the critical level, above which the infection of fish becomes a problem, assuming that such a level exists, and a small change in seal numbers could result in a large change in infection rate. In other areas, the density may be well above or below the critical level, and small changes in seal numbers would have little effect on infection or on processing losses.

In one sense, these regional differences might simplify management because, if the effects of changes in overall seal numbers are averaged over a

number of areas, it becomes more likely that the relationship between infection and losses will be reasonably close to proportional. In another sense, however, management becomes more complex. If the desire is to have the biggest effect on the losses, while at the same time minimizing the costs of management, including the numbers of seals that might have to be culled as part of the management program, then it will be important to concentrate on those particular areas and groups of seals where the benefits will be greatest.

The question of reducing seal populations is considered further in Chapters 29 and 30.

Conclusions

1. Several species of nematode parasites, principally *Pseudoterranova decipiens*, but also *Anisakis* spp., occur in the flesh of cod and other commercial fish in Canadian waters.

2. *Anisakis*, and to a lesser extent *P. decipiens*, can produce the disease Anisakiasis in humans, usually through eating raw fish. Given the usual methods of preparing fish in Canada, this disease is likely to occur very rarely.

3. Marine mammals are the final hosts of these nematodes, which pass through crustaceans or other invertebrates before infecting fish. Seals, especially grey seals, are the most important final hosts for *P. decipiens*. Cetaceans are more important for *Anisakis*.

4. There are strong correlations, on both sides of the Atlantic, between areas of high density of seals, especially grey seals, and infection rates in fish. During the last 30–40 years there have been parallel trends of increasing numbers of grey seals and rates of parasite infection. Both sets of data suggest that increases in seal populations will result in increased infection.

5. The presence of nematodes in fish flesh causes losses to the fishing industry due to the increased processing costs involved in detecting and removing the nematodes and the reduced value of the final product. The current extent of these losses is estimated at over $30 million annually on the Atlantic coast. Smaller losses occur on the Pacific coast. Losses increase with increasing infection, but probably not proportionately.

6. In many areas of eastern Canada where *P. decipiens* is plentiful, catches of cod are rejected for filleting because removal of the parasite is costly, and nematode numbers would exceed Department of Fisheries and Oceans tolerance levels even after candling. The rejected fish are either salted or sent to a meal plant. These practices result in considerable losses, both for processing plants and for fishermen. The American plaice that are caught in some areas near Sable Island are so highly infected that they could not profitably be candled for sale as fillets.

7. Modern methods for the detection and removal of nematodes from fish flesh may have promise for extracting a higher proportion of these parasites and for reducing costs. However, these mechanized methods may be too expensive for small plants to undertake; and even with the best methods, the costs will remain high.

8. Because of the lengthy life-cycle of *P. decipiens*, it may be many years before changes in seal numbers, or other factors that might affect the dynamics of the parasite population, are fully reflected in the infection rate in fish.

9. Though the dynamics of the *P. decipiens*–fish–seal system are not well understood, it is highly likely that increased numbers of seals will result in increased infection, and increased infection will result in increased losses, possibly including increases in the extent of the areas in which commercial fishing for the fresh fish trade for some species is impracticable. Grey seal numbers are increasing, and this is likely to increase losses above the present level.

10. There is no sure way, with present knowledge, to reduce the rate of infection. It is possible that changing the abundance or the size and age composition of the fish populations, or actions aimed at other intermediate hosts might be effective. On present evidence, however, the measure offering the best chance of success would be to reduce the number of seals, especially grey seals. A considerable reduction in seal numbers would probably be needed before any demonstrable effect could be observed in the numbers of *P. decipiens* in fish.

Recommendations

1. Further research on all aspects of the *P. decipiens* problem is urgently needed, particularly to establish more reliably the likely form of the

relationship between the numbers of seals of different species and the frequency of infection, and between infection rate and losses to the industry. Areas of research that seem likely to be useful include: studies of the occurrence of parasites in harp seals; studies of the changes in frequency of occurrence with age or size of fish; detailed study of the geographical distribution of parasites in fish and seals; and the development of models of the dynamics of the seals–fish–parasite system. Consideration should be given to experimental control of seals in a small area in order to gain more insight into the dynamics of the *P. decipiens* problem.

Appendix

Appendix 26.1 Costs and Loss of Revenue Suffered due to *P. decipiens*, 1984

		Units	Nfld.	N.S.	Total
Cod					
1.	Proportion of landings from high infection areas		.09	.46	.21
2.	Napes as proportion of fillets		.10	.10	.10
3.	Fillets from all areas	lb M	153.47	66.98	220.45
4.	Fillets from high-infection areas (1×3)	lb M	13.81	30.81	43.62
5.	Napes from all areas (2×3)	lb M	15.35	6.70	22.05
Candling of Fillets					
6.	Direct labour costs per lb	$	.05	.08	.06
7.	Direct labour costs (3×6)	$M	7.52	5.36	12.88

Appendix 26.1 Costs and Loss of Revenue Suffered due to *P. decipiens*, 1984 (continued)

		Units	Nfld.	N.S.	Total
8.	Proportion of direct labour costs attibutable to *P. decipiens*		.90	.98	.93
9.	Direct labour costs attributable to *P. decipiens* (7×8)	$M	6.77	5.25	12.02
10.	Variable overhead costs as proportion of direct labour costs		.25	.25	.25
11.	Variable overhead costs (9×10)	$M	1.69	1.31	3.00
12.	Total costs (9+11)	$M	8.46	6.56	15.02
Candling of Napes					
13.	Proportion candled if no parasites other than *P. decipiens*		.75	.50	.67
14.	Napes candled (5×13)	lb M	11.51	3.35	14.86
15.	Direct labour costs per lb.	$	.05	.08	.06
16.	Direct labour costs (14×15)	$M	.58	.27	.84
17.	Variable overhead costs as proportion of direct labour costs		.25	.25	.25
18.	Variable overhead costs (16×17)	$M	.14	.07	.21
19.	Total costs (16+18)	$M	.72	.33	1.05
Downgrading of Fillets					
20.	Proportion from high infection areas downgraded		.25	.25	.25

Appendix 26.1 Costs and Loss of Revenue Suffered due to *P. decipiens*, 1984 (continued)

		Units	Nfld.	N.S.	Total
21.	Fillets downgraded (4×20)	lb M	3.45	7.70	11.16
22.	Loss of value per lb	$	.40	.40	.40
23.	Loss of value (21×22)	$M	1.38	3.08	4.46
Discard of Napes					
24.	Proportion discarded (balance after deducting 15)		.25	.50	.36
25.	Napes discarded (5×24)	lb M	3.84	3.35	7.19
26.	Current price/lb	$	.64	.64	.64
27.	Price/lb fall if none discarded	$	.13	.13	.13
28.	Price/lb if none discarded (26−27)	$	.51	.51	.51
29.	Revenue lost from discarded napes (25×28)	$M	1.96	1.71	3.66
30.	Gain due to present enhanced price caused by discard (14×27)	$M	1.50	.44	1.93
31.	Net revenue lost (29−30)	$M	.46	1.27	1.73
32.	Direct labour saved by not candling (15×25)	$M	.19	.27	.46
33.	Variable overhead saved by not candling (17×32)	$M	.05	.07	.11
34.	Net revenue lost (31−32−33)	$M	.22	.94	1.16
Flatfish					
35.	Fillets	lb M	–	13.65	13.65

Appendix 26.1 Costs and Loss of Revenue Suffered due to *P. decipiens*, 1984 (continued)

		Units	Nfld.	N.S.	Total
36.	Direct labour costs of candling per lb	$	–	.06	.06
37.	Direct labour costs (35×36)	$M	–	.81	.81
38.	Proportion of direct labour costs due to *P. decipiens*		–	.60	.60
39.	Direct labour costs due to *P. decipiens* (37×38)	$M	–	.49	.49
40.	Variable overhead costs (19×43)	$M	–	.12	.12
41.	Total costs (39+40)	$M	a	.61	.61
Other Groundfish					
42.	Fillets	lb M	35.00	60.00	95.00
43.	Costs per lb	$	.04	.04	.04
44.	Total costs (42x43)	$M	1.40	2.40	3.80
All Groundfish					
45.	Claims due to excessive *P. decipiens*	$M	.10	.10	.20
46.	Cost of training candlers	$M	.15	.15	.30
Summary					
47.	Candling fillets of cod (12)	$M	8.46	6.56	15.02
48.	Candling napes of cod (19)	$M	.72	.33	1.05
49.	Downgrading fillets of cod (23)	$M	1.38	3.08	4.46
50.	Discard of napes of cod (34)	$M	.22	.94	1.16

Appendix 26.1 Costs and Loss of Revenue Suffered due to *P. decipiens*, 1984 (continued)

		Units	Nfld.	N.S.	Total
51.	Candling flatfish (41)	$M	a	.61	.61
52.	Candling other groundfish	$M	1.40	2.40	3.80
53.	Claims due to excess P. decipiens (45)	$M	.10	.10	.20
54.	Training costs (46)	$M	.15	.15	.30
55.	Total costs & losses (47 to 54)	$M	12.43	14.17	26.60

Source: Adapted from George (1986).

a. Flatfish landed in Newfoundland are not significantly affected by *P. decipiens*.
M = 1 million.

Sources of Data and Notes on Computations

1. From data supplied to Atlantic Steering Committee on Parasites (ASCP) by processors.
2. From Task Force on Seal Borne Parasites (Canada, DFO, 1983, p. 4). and processing companies.
6. From processors.
8. An arbitrary assessment to recognize that some (a minor part) of direct labour costs may be attributed to *Anisakis*. A greater proportion of parasites in fish landed in Newfoundland is *Anisakis* than is the case in Nova Scotia.
10. From processor. When a badly infected batch of fish arrives in a plant, processing takes longer and variable overhead costs, such as wages of workers not on the production line, are greater than they would be for a good batch. It is appropriate, therefore, to assign such variable overheads. However, no provision is made for fixed costs. The frames used for candling are cheap, and their annual cost is insignificant. Moreover it appears unlikely that building size would have been greater to accommodate the frames. In any event, frames would usually have to be installed to candle for *Anisakis* and grubs. Further, fish processing is not a capital-intensive operation, and all fixed costs only amount to about two cents per pound of processed fish.
13. Based on data supplied to ASCP by processors, but Newfoundland figure has been increased since *Anisakis* is the main cause of napes of cod from Area 2J and 2KL being discarded.
15. From estimates supplied by fish processors to ASCP. The figure for Newfoundland was 25 cents, but since this referred to cod from an area as free of *P. decipiens* as any, and as

Appendix 26.1 Costs and Loss of Revenue Suffered due to *P. decipiens*, 1984 (continued)

Newfoundland cod is generally less infected than cod landed in Nova Scotia, it was assumed that most of this cost derived from *Anisakis*.

20. From data supplied by a fish processor to ASCP.
22. See item 20.
26. See item 20.
27. Estimate of fall in market price of processed napes if supply were increased as a result of processing all napes.
30. Napes presently marketed fetch a higher price because supply is restricted by *P. decipiens*.
36. Assumed to be same as for cod (line 8).
37. Processor's estimate for Nova Scotia. No entries appear in lines 35–41 for Newfoundland because *P. decipiens* is not present to a significant extent in flatfish landed in that province.
38. Estimate. The remaining 40% is assumed to be attributable to grubs, which occur in great quantities in flatfish landed in Nova Scotia from some fishing areas.
45. Based on experience of processor.
46. Estimate of processor.

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PART VI

Management Issues

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Chapter 27

Objectives of Resource Management

Good management requires clear objectives. Contrasting views about objectives were presented in evidence to the Royal Commission. Some of those giving evidence viewed seals primarily in economic terms, as a resource to be managed in order to maintain a high economic return either from the sale or direct consumption of seal products, or from fisheries (e.g., Government of Newfoundland and Labrador, 1985; Indigenous Survival International, 1985). Others believed that seal management should be more concerned with the seals themselves, and that interference should be kept to a minimum (e.g., Bøe, 1985; T.H. Scott, 1985). The choice and balance between such objectives must be a political decision, but this decision will be helped by an examination of some principles of resource management and of the specific objectives that might be pursued if seal management is viewed primarily in economic terms. The latter examination is divided between objectives in managing a single species and the broader questions of what has been called "ecosystem management".

Management and Conservation Principles

Many organizations have stressed the importance of conservation principles as part of management policy. A rational consideration of all the issues involved in the conservation of seals as a resource leaves no doubt that management policies must be consistent with sound conservation principles; the connection is emphasized by briefs and by the statements made by intervenors to the Royal Commission (e.g., de Haes and Miller, 1984; Hummel, 1984; Fox, 1985).

The International Union for the Conservation of Nature and Natural Resources (IUCN) is an international organization with individual members in 115 different countries (R.F. Scott, 1985). Canada is one of close to 60 countries which are members, and over 120 government agencies, including several from Canada, are also members. The membership also includes almost 340 non-government organizations, both national and international. The World Conservation Strategy prepared by the IUCN, with the support of the United Nations Environment Programme, the World Wildlife Fund, the Food and Agriculture Organization of the United Nations and the United

Nations Educational Scientific and Cultural Organization, defines conservation as:

> *. . . the management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations (IUCN, 1980).*

The World Conservation Strategy recognizes that sustainable utilization of species is compatible with conservation. Such utilization, however, must be based on a scientifically justified management plan.

The World Conservation Strategy sets out three explicit objectives in resource conservation. They are:

- to maintain essential ecological processes and life-support systems on which human survival and development depend;

- to preserve genetic diversity;

- to ensure the sustainable utilization of species and ecosystems.

In considering seals as a harvestable resource and analysing the management approaches to their conservation, the Royal Commission has taken account of the view that seals should be looked upon as more than mere sources of meat, skins and oil. Clark (1981, p. 104) states that "Objectives leading to the overexploitation of species or the unwise use of the physical and other resources they provide receive little sympathy" and that "An approach to the natural world which views it simply as a supermarket is likely to lead to poor conservation and management . . ."

The International Council of Environmental Law (ICEL, 1985) fully endorses the principles set forth in the World Conservation Strategy. Its concern is primarily "to ensure that the taking of seals in the Canadian Arctic is so carried out as not to endanger the sustained viability of species or populations and not to impose significant distortions on the ecosystems of which the seals taken form a part." ICEL directed the Royal Commission's attention to Principle 4 of the World Charter for Nature adopted by the General Assembly of the United Nations on 29 October 1982 which states:

> *Ecosystems and organisms, as well as the land, marine and atmospheric resources that are utilized by man, shall be managed to achieve and maintain optimum sustainable productivity, but not in such a way as to endanger the integrity of those other ecosystems or species with which they co-exist.*

The World Wildlife Fund (Canada) brief to the Royal Commission, recognizing that utilization of seals is compatible with their conservation, lists the following prerequisites for such utilization: that the total allowable catch not endanger the herd, that waste be avoided and that, if seals are killed, they are killed humanely (Hummel, 1984).

The Committee on Seals and Sealing (COSS) advises the Minister of Fisheries and Oceans. In its brief to the Royal Commission, COSS (1985) restates its basic guideline, adopted when the committee was established in 1971, that the killing of seals must be humane, ecologically sound and economically viable. COSS sees no reason to change these requirements, as it considers them a sound basis for the management of the harp seal as a natural resource.

These viewpoints are incorporated in Canadian government policy as stated in the Department of Fisheries and Oceans brief to the Royal Commission:

> *Seals are considered a natural renewable resource available to be humanely harvested within the limits of sound conservation principles, taking into account its role in the ecosystem, with the objective of gaining the maximum socio-economic benefits for Canadians in general, and those who depend directly on the resource in particular (Canada, DFO, 1985).*

The Royal Commission accepts the principles of management set forth in these declarations of national and international organizations.

In order to move from these general principles to more specific objectives relating to the numbers of seals that should be allowed to be killed, or a target level of total seal abundance, it is helpful to look first at

the individual species or stock of seals (i.e., to undertake single-species consideration) and then at these species in their environmental setting.

Single-Species Harvest

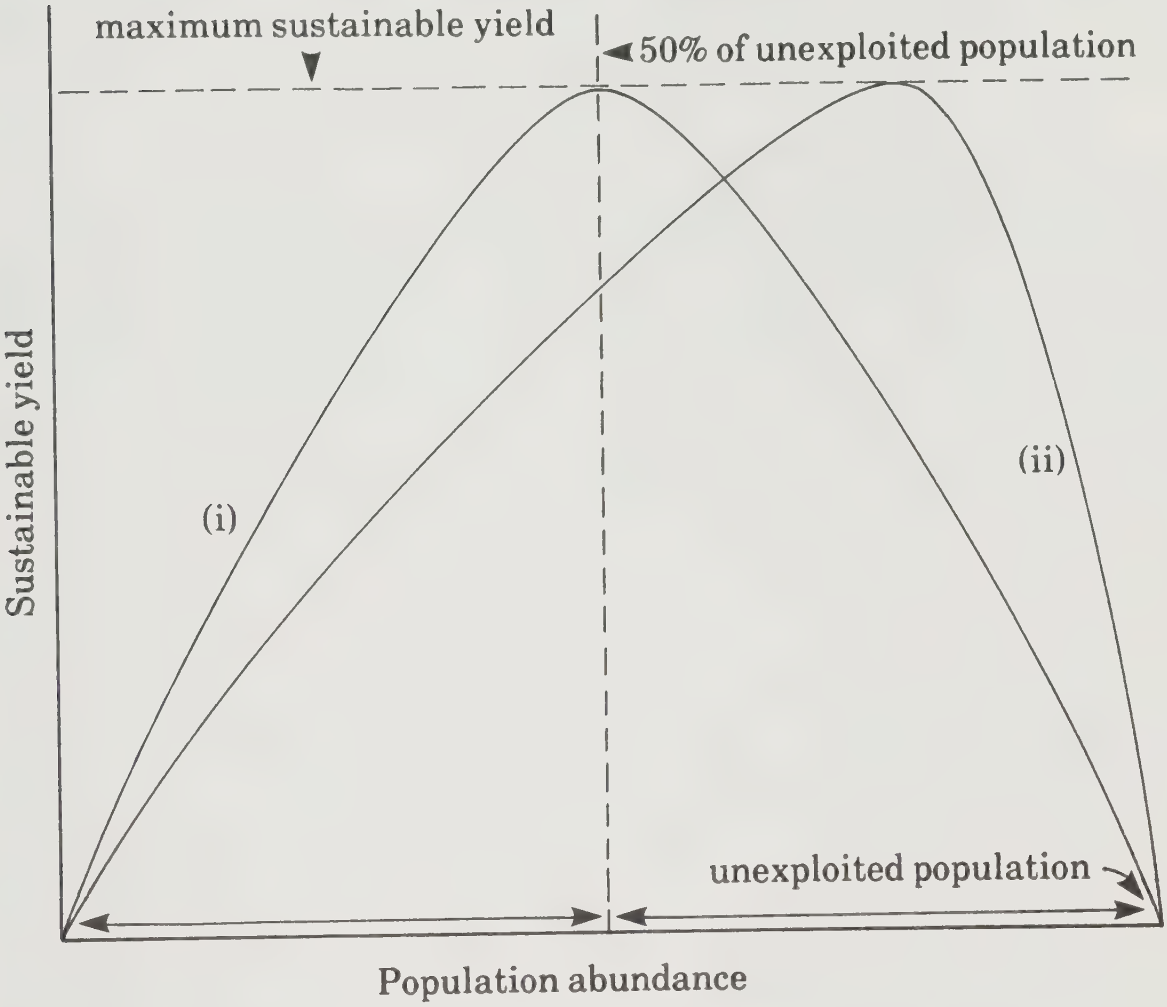
Correct management policy and appropriate target levels of population have been extensively considered in relation to commercial fisheries (e.g., Gulland, 1968; Roedel, 1975; Larkin, 1977). If these fisheries concentrate on harvesting a single species, reasonably direct and simple relationships can be predicated between the amount of fishing, the abundance of the stock and the sustainable yield. The abundance of the stock declines steadily with increasing fishing. The sustainable yield is small if fishing is light and abundance high, as well as when fishing is very intense and abundance low. It reaches a maximum (that is, the maximum sustainable yield, or MSY) at intermediate levels of fishing and stock abundance. For marine mammals the population level giving MSY is often at, or slightly above, half the unexploited abundance.

The sustainable yield exists because the population responds to exploitation. In the absence of harvesting, the population will be in some rough balance with the carrying capacity of the environment, and the number of births will be equal – at least as an average over time – to the number of deaths from disease, predation and other natural causes. Standard ecological theory holds that if harvesting reduces the population below this equilibrium level, conditions will be rather more favourable for the surviving seals. Their effective reproductive rates will increase or their natural mortality rates will decrease, or both, so that there will be a surplus of births over deaths arising from natural causes and a tendency for the population to increase. If the number of seals killed by humans equals this natural increase, the population will remain unchanged and that level of yield will be sustainable indefinitely.

At very large population sizes, the rate of increase will be small, with the result that the sustainable yield will be small. It will also be small at very small population sizes. It will stand at its maximum (MSY) at some intermediate point, with a moderate-sized population. (See Figure 27.1.)

The population level at which MSY occurs, expressed as a proportion of the initial unexploited population, will depend on the nature of the response of the population to changes in abundance. Assuming a simple linear

Figure 27.1
Two Theoretical Sustainable Yield Curves



response, that is, a rate of increase that decreases linearly with increases in population abundance, MSY will occur at exactly half the population. (See Figure 27.1, curve (i).) It is commonly believed (see, for example, many contributions to the Scientific Committee of the International Whaling Commission) that MSY for marine mammals occurs at a higher population level because the response is uneven and concentrated at the higher levels of abundance. (See Figure 27.1, curve (ii).)

The sustainable yield, expressed as actual numbers, from a stock of seals, will, for a given population size, depend on what ages and sexes of seals are harvested. An adult female will contribute more to the population in its next few years of life than a pup, which may not breed for five or six years. Killing a given number of females will therefore have the same impact on the population as killing a substantially larger number of pups, which means that the sustainable yield of seals taken as pups is larger than the sustainable yield of adults. The precise arithmetical equivalents for a range of situations are calculated in Chapter 21, Appendix 21.1. For animals that

maintain harems, such as fur seals and sperm whales, the situation is more complicated. Provided that enough males are left to satisfy the females, an appreciable number of males can be taken without reducing the breeding rate or the number of pups born. (See Chapter 22.)

Taking MSY while keeping the population at the MSY level is an obvious management option, and one that has been written into a number of fishery-management agreements. It does have disadvantages, however, and it is now generally rejected as a preferred management objective (Larkin, 1977). If, for example, the stock abundance varies because of environmental changes, attempts to take exactly MSY each year can lead to dangerous instability. Maintaining the population at a level a little above that which produces MSY can reduce this risk and has other benefits, such as higher catches per unit effort and hence better economic performance.

It has therefore become common to consider the population that produces MSY as a lower limit of the acceptable target level, and to aim for what has been called "optimum yield" and the "optimum sustainable population" (OSP). This concept is entrenched in the United States *Marine Mammal Protection Act of 1972*, which is an ambitious attempt to codify national policy for the management and conservation of marine mammals and is relevant to Canadian policy considerations. Section 3(9) of that Act defines optimum sustainable populations as "the number of animals which will result in the maximum productivity of the population of species, keeping in mind the optimum carrying capacity of the habitat and the health of the ecosystem of which they form a constituent element". If productivity means "net productivity" in the sense of the amount produced less natural losses, it seems to be equivalent to MSY. If it means gross production, that is the total number of births, it probably occurs at the maximum, unexploited, population abundance.

In practice, OSP and the U.S. legal requirement that populations not fall below OSP have been interpreted as designating a range extending upwards from MSY, which means that the population should be maintained at the level giving MSY or at a higher level. Because the maintenance of a population at the OSP or within OSP range is a legal requirement in the United States, it is of both theoretical and practical interest. It affects, for example, any question of exporting marine mammal products to the United States. Since a population might be maintained at a level well above that producing MSY, and since at that level the sustainable yield may be small, the concept of OSP recognizes that achieving a high physical yield is not the only possible objective of management. However, if management abandons

high physical yield as its prime objective, there seems little reason to keep the MSY level as the lower bound of target-population levels. If there are reasons, such as the reduction of competition between seals and fishermen, favouring a relatively small seal population, then a population well below that producing MSY might be acceptable, provided that it is not so low as to threaten the continued existence of the stock.

An objective similar to OSP and closely tied to MSY has been adopted by the International Whaling Commission (IWC) in its New Management Procedure. This procedure prohibits virtually any catching of whales from stocks below those producing MSY. Stocks at or above the MSY level can be harvested, and the details of the procedure, which includes some allowances for uncertainty, imply that the abundance will tend to a level somewhat above that giving MSY, that is, in the OSP range. The procedure makes very high demands on the information about stock sizes and sustainable yields, and the IWC has found it virtually impossible to obtain sufficient information to apply it.

In certain circumstances (low costs of harvesting, high discount rates which give little economic weight to costs or benefits that occur in the distant future, and low population rates of increase), narrow economic interests could favour action to deplete a population to levels well below that producing MSY, possibly even to extinction (e.g., Clark, 1976). In these circumstances, better returns flow from a large immediate harvest, the proceeds of which earn interest, than from a possibly larger harvest to be taken some time in the future.

National policy obviously should give full weight to future interests, and the argument for taking high short-term yields is not a valid reason for abandoning MSY for seal stocks as a minimal management option. In any case, MSY and its near relatives, such as OSP, are reasonable objectives only if the animal population functions as an economic resource. If the product lacks a market, or if the costs of harvest exceed the value of the product, there is no purpose in considering ways to maximize the yield.

Other Considerations

The Royal Commission has been given various reasons for not adopting MSY or OSP for seal stocks. To most Canadian fishermen, for example, seals are pests, some species more so than others (e.g., Eastern Fishermen's Federation, 1985; Fisheries Association of Newfoundland and Labrador, 1985). They spread parasites, damage fishing nets and compete with fisher-

men for fish. However, no suggestion was made to the Royal Commission by any group that they would like to see seals exterminated because they are a pest. Fishermen accept seals as part of the natural system and are fully prepared to live with a "reasonable" population of seals, although they definitely prefer a small seal population to a large one. What represents the size of a "reasonable" population of any specific stock of seals or, to put it another way, the level of abundance above which a stock of seals causes an unacceptable amount of damage, is not clear. It is possible that a modified benefit-cost analysis, in which the marginal costs of keeping down the seal population are balanced by the marginal benefits of limiting the damage caused by seals to the fisheries, might shed light on this question. It should be emphasized, however, that such an exercise is based solely on economic criteria.

Possible relations between seal population abundance and the loss to fisheries are sketched in Figure 27.2. The loss of or damage to gear might be proportional to the abundance (curve (i)). The relation could be more complex (curve (ii)), as might be the case for infection by *P. decipiens*. Such costs as those of candling and trimming might increase slowly at first, when the infection is not noticeable, then increase rapidly as the infection rate makes the candling of each fillet necessary, and later increase slowly.

The two relations (of sustainable harvest and losses to fisheries) can be combined, in dollar terms, for example, to give the net economic effect of seals. The net benefit will be the difference between the positive return from the seal harvest (e.g., the curve (i) of Figure 27.1, repeated as a broken line in Figure 27.2) and the losses to the fishing industry (curves (i) and (ii) in Figure 27.2). These are shown in Figure 27.3, using curve (i) of Figure 27.1 and the two curves of Figure 27.2. As drawn these have their highest points at a population size less than that corresponding to MSY. This will always be true for likely relations, providing that positive benefit is possible. These curves should be treated as illustrations. Because other factors such as discount rates and costs of catching seals need to be taken into account, the maximum in this curve will almost certainly not be the optimum, even in economic terms. It will, however, be nearer such an optimum than MSY.

MSY has not played a critical role in the circumstances of Canadian sealing. Most participants in the sealing industry, especially the Inuit and sealers in the outports of Newfoundland, whose interests are directly affected, have been concerned with harvesting and selling enough seals and seal products to satisfy immediate economic needs. Their costs of harvesting probably have changed little with changes in stock abundance, and so a high

Figure 27.2
Possible Relations Between Seal Population and Losses to Fisheries

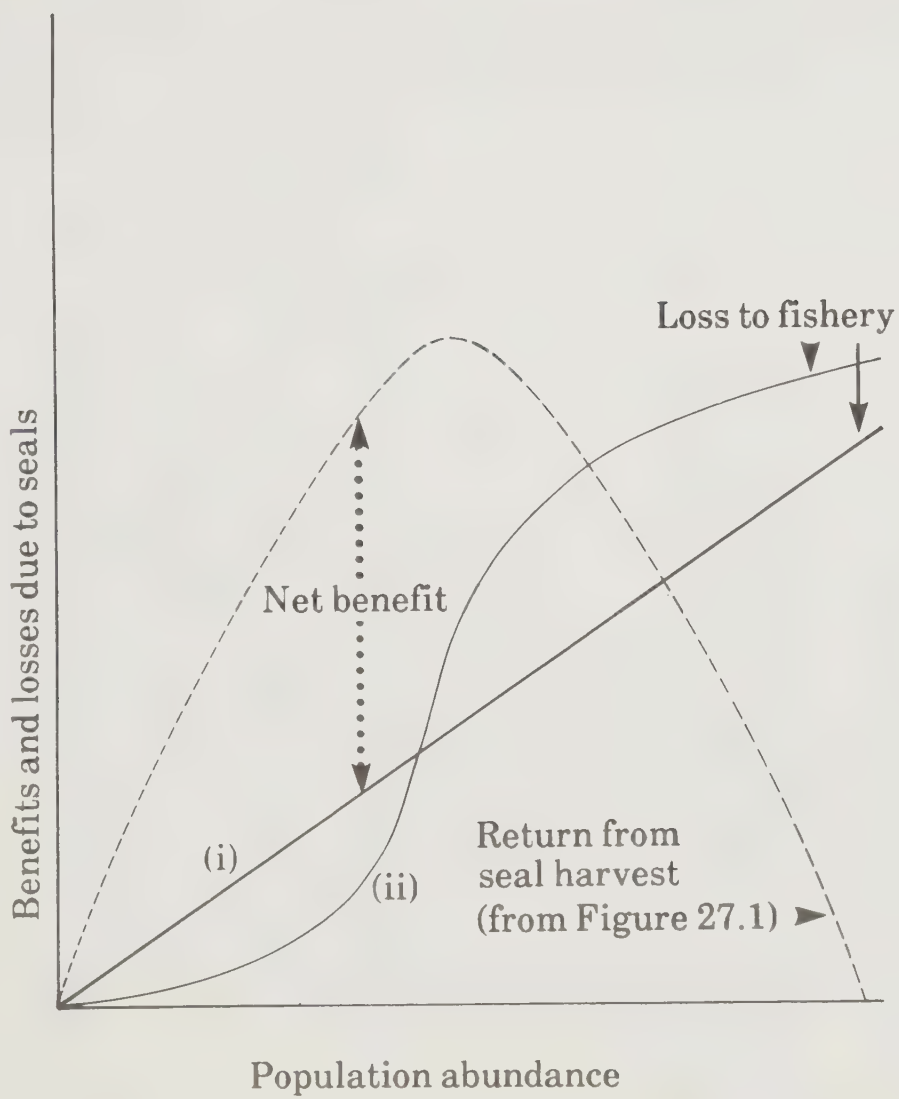
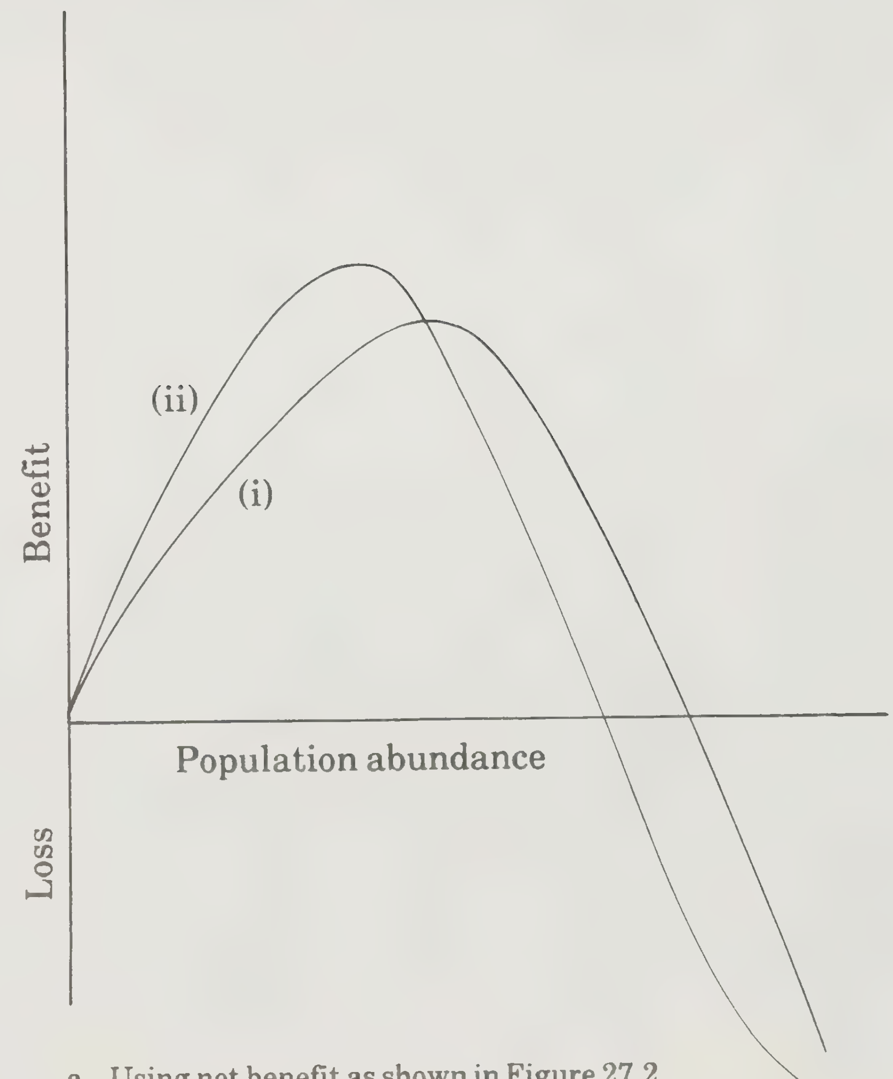


Figure 27.3
Net Economic Effect of Seals[a]



a. Using net benefit as shown in Figure 27.2

stock abundance is not important to their economic success. While each individual sealer would like his harvest to be high, it does not seem to be particularly important to keep the total harvest as high as possible.

Thus there are difficulties, even in simple single-species economic terms, of defining a unique target level for population abundance. Instead of looking to see whether a proposed management action moves the population towards some poorly defined optimum, one might examine the benefits and costs of the proposed action and then compare them with the benefits and costs of other possible actions, including the possibility of doing nothing or that of maintaining the present policy. Any upward change in population numbers will involve some costs (e.g., more seals will eat more fish) and can produce some benefits (e.g., more seal products, more seals to watch and enjoy), even though not all the "costs" and "benefits" can easily be expressed in simple economic terms. Many of the factors affecting costs and benefits will change, for example, with changes in the market for seal products or in the weight given to the "benefit" of having more seals in the sea. Thus the optimum, taking all factors into account, is unlikely to be constant.

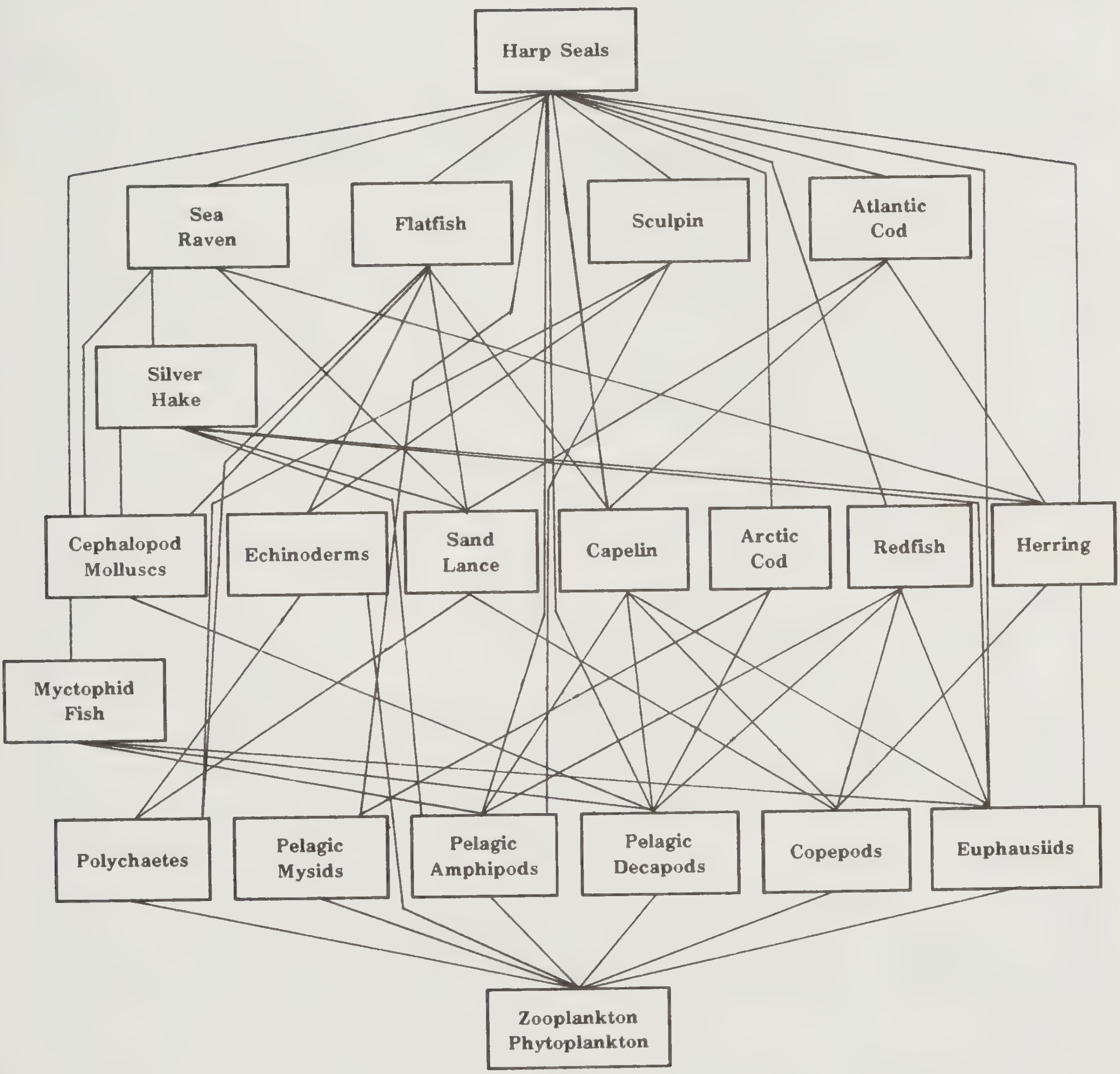
Ecosystem Management

Seals do not live in isolation. Any interventionist policy for managing seals and sealing should take account of their interactions with the other species that make up the ecosystem in which they live. An ecosystem consists of all the constituent elements that affect it and, in the case of seals, includes the following elements:

- the seals themselves;
- other marine mammals;
- all fishes in the water inhabited by the seals;
- the plants that feed the animals on which the fish feed;
- the salinity and other chemical constituents of the water;
- geographic and climatic features such as the proximity of land, the presence of ice and variations in temperature.

All these elements interact, and such interactions are complex. For example, Figure 27.4 illustrates just one kind of interaction: that among harp seals, the animals on which they feed and the food of the latter.

Figure 27.4
Simplified Trophic Web for the Harp Seal



Source: Lavigne et al. (1982)

The public and scientists are much more aware of the importance of these interactions than they have been in the past, and this awareness is reflected in the emphasis now being given to the concept of ecosystem management to complement, rather than replace, single-species approaches. To some extent, criticisms of single-species approaches are unfounded, since the models used implicitly take account of the interactions with other species, for example in determining the values of the carrying capacity used in the simple production type of model. However, a more explicit recognition of ecological relations is needed. To examine this question the World Conservation Strategy is again considered.

The conservation and management principles set out in the World Conservation Strategy and cited at the beginning of this chapter focus concern on genetic diversity, human need and the maintenance of essential ecological processes. Provided that the total populations are not so reduced as to impoverish the gene pool, genetic diversity is not threatened by recent Canadian sealing policy, inasmuch as sealing, especially the taking of pups, is unselective. The objective of ensuring a sustainable utilization of species and the ecosystem reflects the long-term interests of sealers and users of seal products. Any policy aimed at managing seals in those interests would need to satisfy this objective. The first objective, that of the maintenance of ecological processes and life-support systems on which humans depend, is not addressed in the preceding treatment of single-species considerations. It is dealt with in the following section.

Maintaining Ecological Processes

Exactly what is meant by maintaining essential ecological processes, and how many seals are required to comply with this condition, is not clear. A decline in numbers of seals would be expected to have some effect on the animals on which they feed. In relation to some species of marine mammal, such an effect could bring about a substantial change in the ecosystem. An example is the predation by sea otters on sea urchins. Sea urchins are very efficient consumers of kelp and, if they are common, kelp is scarce. A reduction in sea otter abundance can virtually eradicate thick kelp beds and change the whole appearance of the ecosystem (Estes and Palmisano, 1974).

There is no evidence that any Canadian species of seal plays such a critical role. Undoubtedly, changing seal abundance will change the relative abundance of other species but, since seals feed on various species of fish, they are unlikely to affect any one species to a critical extent. At the same

time, their catholic diet may play an important role in damping out large fluctuations by switching attention towards any unusually abundant species and away from species in decline. However, these effects seem unlikely to be so important that a decline in seal stocks would affect essential ecological processes.

A suggestion was made in evidence to the Royal Commission that seals play an essential role in the ecosystem because the nutrients they excrete are vital in maintaining primary productivity (Watson, 1985). Seals do recycle some nutrients, but the amounts constitute a very small proportion of the total nutrient supply from recycling through animals or from other sources (upwelling, river inflow, etc.) If there were no seals, the animals seals eat would themselves be recycling nutrients. It is hardly conceivable that the abundance of seals has any influence on primary production or, through it, on the other elements in the ecosystem.

A pervasive misconception sometimes used as an argument for killing seals is that seals need to be controlled for their own good or for the good of the ecosystem. According to this view, the absence of hunting will lead to overpopulation and serious damage to the ecosystem. Since seals existed without endangering the ecosystem for a long time before people started to hunt them, this argument seems faulty. There have been instances where the population of a large mammal has expanded so rapidly as to cause serious damage; elephants in African national parks afford an example. High population growth seems to have negative effects only under certain conditions: when the animals can cause long-lasting physical damage to the environment and especially to the plants on which all later production depends (e.g., destruction of trees by elephants), when the animals are confined in a restricted area such as a national park or on an island, and when the expansion is triggered by a sudden change in conditions so that the population expands too fast for normal density-dependent controls to take effect. For a full discussion of the scientific problems of over-abundant species, see Jewell and Holt (1981).

These conditions, except possibly the last, do not apply to seals in the sea. The first may apply when seals come ashore to breed. Grey seals on the Farne Islands in the North Sea have occurred in such high densities on the most favoured islands that they have destroyed the vegetation and the breeding sites for puffins (Bonner and Hickling, 1971). A similar conflict between the expanding fur seal population and breeding albatrosses may be arising on one of the islands around South Georgia. In these cases a by-product of the early exploitation has been to change the geographical distri-

bution of the stocks so that the same total numbers can cause problems of overabundance in some restricted localities. This problem does not seem to affect any Canadian seal population. Boal (1980) reports a case of some effect of harbour seals in California on the algae and other organisms on the rocks on which they haul out, but the extent of this effect on the area as a whole seems to be trivial. If the problem did exist in Canada, there might be solutions, such as disturbance or barriers, other than killing seals.

It is also argued that, at the high population densities which would probably occur if there were no hunting, the seals would suffer a higher incidence of disease, reduced breeding success and other negative effects. Undoubtedly, some changes of this type would occur. Unless they did, the population would increase without limit. Such density-dependent changes are entirely natural. To the extent that at a high density some biological features of populations, such as mortality and breeding success, change with negative effects, it would be reasonable to talk about a stock suffering from overpopulation.

What should properly be termed "overpopulation" depends on the viewpoint. To a sheep farmer or a cattle rancher, most national game parks are badly overpopulated. There is less vegetation, and the animals are in poorer condition, than would be the case if the abundance were kept lower by harvesting or culling. A larger crop of animals would be possible at a lower population. However, the situation does not represent overpopulation in the sense that there are more animals than would exist under natural conditions undisturbed by humans, or that action should be taken to reduce their number or to prevent the abundance reaching such a high level. The farmer or rancher probably envisages some population level similar to MSY, when net production or sustainable yield is high. This population will be smaller than the unexploited abundance level.

Apart from the question of natural ecological processes, it can be argued that overpopulation may cause distress to individual animals. Some density-dependent changes, such as a delay in the age at maturity, may slow down or halt a population increase but have little effect on the well-being of the individual animals. Others, such as increased disease or greater injury from intra-specific competition, presumably make life less pleasant for the individual seal.

At this stage, other considerations enter the picture, some concerning fundamental attitudes to the relation between people and other animals. If humans have dominion over animals and dominion includes the responsi-

bility to adjust matters, where possible, to minimize the aggregate discomfort experienced by seals or other animals, culling to reduce harmful effects of overcrowding might be argued for. On the other hand, if people should refrain from interfering with animals unless their intervention is absolutely essential, a cull should not take place. Almost certainly, a decision will take account of other factors. A significant factor in deciding on a cull on the Farne Islands in the 1970s was the shock to human visitors of seeing large numbers of starving pups (Bonner, 1982).

Associated and Dependent Species

The wider ecological effects of harvesting one species include possible consequences to other non-target species associated with, or dependent on, the target species. Concern has been expressed in connection with the growing krill harvest in the Antarctic. It is feared that, if this harvest increases, the reduction in the abundance of krill would harm the many species for which krill is the major food item and, in particular, might threaten the recovery of the large baleen whales. These concerns and the objectives that should be followed in such a situation are spelled out in the Convention establishing the Commission for the Conservation of Antarctic Marine Living Resources. Of special interest is Article II, which is probably the most careful attempt to codify the principles of ecosystem management. This, *inter alia*, requires (Article II 3(b)) the maintenance of the ecological relationships between harvested, dependent and related populations of Antarctic marine living resources.

The Antarctic case relates to the effect on predators of increased exploitation of a prey species. Probably the only predators that might be affected by a high seal harvest are the polar bears that prey on ringed seals. There is no evidence that the effect on polar bears of too high catches of ringed seals should be a matter of major concern.

Much more concern has been expressed about the effect of a reduced seal harvest, and hence increased seal numbers, on the species that seals eat. It is highly unlikely that increasing numbers of seals will significantly disrupt the ecosystem. Seals have co-existed with their prey for millions of years. The real issue is that more seals may mean less fish for fishermen. This conflict is discussed in detail in Chapter 24. Where seals and men catch the same species of fish, increased numbers of seals will mean a smaller catch for fishermen, but the arithmetic of the matter is not simple. The loss in catch is unlikely to be exactly equal to the weight of fish eaten by seals. It

might be more or a great deal less. Factors that affect the answer include the sizes of fish taken by seals and fishermen, the times and positions of the seals' consumption relative to the fishery and whether the consumption by seals of non-commercial species has any indirect effect on fishing success. These factors will vary among species of seals and from fishery to fishery, and the effects must be estimated separately for each fishery.

With respect to managing the ecosystem as a whole, there is no uniquely or objectively "correct" abundance of seals. Despite differences in seal abundance, the essential features of the ecosystem are the same, and there is no compelling ecological reason to take action either to increase numbers by restricting the harvest or to reduce numbers by culling.

Uncertainty and Variability

Two factors not explicitly considered in the preceding sections are the uncertainties in any estimates of population size or population parameters, and the variability in the natural environment. Recent considerations of policies for managing marine mammals and marine resources generally have emphasized these factors. For example, a statement on new principles for the conservation of wild living resources (Holt and Talbot, 1978) has as its second principle, "Management decisions should include a safety factor to allow for the facts that knowledge is limited and institutions are imperfect." The IWC, under its New Management Procedure, deliberately set quotas below the estimate of MSY.

Both these examples argue that because of uncertainties, catches should be less than amounts that scientific estimates, taken at their face value, would permit. The same view is that for too long, the perceived interests of fishermen and sealers have been given too much weight. Then, in cases of doubt or uncertainty, catches tended to have been set at the upper end of a given range, allowing fishermen the benefit of the doubt. Now many persons believe that seals and other marine mammals should be given the benefit of the doubt, and that catches should be set deliberately low. The scientific basis for this argument is that the effects of management are not symmetrical. High catches can, at their worst, render the stock extinct, and thus be irreversible. It may take a very long time for an overexploited stock to recover. The effect on a stock of taking too little can, however, be quickly corrected by a short period of high catches.

For serious errors, which involve large departures from the desired condition, this asymmetry definitely exists and justifies a definite bias to-

ward setting catch quotas or similar controls lower than the best or central estimate. The asymmetry usually arises because the effects on future sustainable yields of acting on over- and underestimates of current sustainable yield are not the same, even when the extent of the over- and underestimates are the same. The drop in sustainable yield arising from an overestimate, and hence excessive catches and falling population, is more serious than that arising from an underestimate and catches below the sustainable yield.

This may not be true for small errors which result in small displacements of the population's target level. For such relatively small changes, there seems no reason to suppose that errors in one direction should be easier to correct by appropriate adjustment to later catches than should errors in the other. Deliberately adjusting allowable catches downwards is, therefore, not necessarily the best reaction to uncertainty, even if it were clear – and it is usually not clear – what size of adjustment would be appropriate for a given degree of uncertainty.

A much better reaction to uncertainty is to develop scenarios of the events that would occur in the worst possible case, as well as for the most likely set of population estimates. Such scenarios would take account of the ability of the management system to detect that the estimates were wrong and to take appropriate corrective action. Proposed action, such as setting a catch quota at a given level, will be acceptable if there is evidence that even under the most unfavourable combination of values, any departure of the population from the desired condition will be detected, and that mechanisms exist which should ensure that effective action will be taken to restore the population to the desired condition, within a reasonable period.

Conclusions

It is not possible to define on biological grounds a unique optimum level of population abundance which should serve as a long-term target of management policy. The MSY level can give a reference level but, taking account of the possibly negative effect of seals on fisheries, the economically optimum population level could be well below the MSY level. Sustainable utilization of the seal population is compatible with conservation.

Account should be taken in principle of the interactions between seals and the rest of the natural ecosystem in which they live. Apart from the possible direct effects of seals on fisheries, these interactions are unlikely

in practice to alter significantly the management policies for seals based on the simple, single-species, biological models.

Some degree of uncertainty will exist in any analysis of a seal stock, and all seal stocks are subject to some variations because of changes in the natural environment. Management policies should take these uncertainties into account.

Given the difficulties of defining an optimum population level, and often of determining the position of the current population relative to that level, attention may be focused on the costs and benefits involved in changing the population size. In focusing on this factor it would be important to include all the social benefits or costs, both direct and indirect, and not just the immediate economic effects.

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Chapter 28

International Aspects

Canada is not the only country with seals, a sealing industry and a seal problem. A review of the experiences with seal management in other countries can put the Canadian situation in some perspective. Moreover, Canada does not act in isolation with respect to its own seal stocks. Some of the stocks are shared with other countries by virtue of the seals' disrespect for international borders. Historically, the products from sealing in Canada have served an international market. Over the years, Canada has participated in joint management of some seal stocks and, in the process, assumed responsibilities within bilateral or multilateral conventions and agreements. This chapter considers some of these international aspects of seals and sealing.

Certain categories of experience in other countries, such as the alternative employment opportunities for Norwegian sealers and for aboriginal peoples in Greenland, are closely related to specific points in the Royal Commission's terms of reference. These categories are discussed in detail elsewhere in the Report. (See Chapter 19.) The present chapter describes other countries' approaches to their seal problems through a series of regional reviews and provides an account of the different international mechanisms used to co-ordinate the management of seal stocks.

Seals and Sealing in Other Regions

Antarctic and Sub-Antarctic Seals

Stocks

The seals of the southern oceans may be conveniently divided into two main groups, the true antarctic seals that breed on ice surrounding the antarctic continent and the fur seals and elephant seals that breed on the islands of the sub-antarctic.

The former group did not become well known until the present century. Their numbers have been estimated as follows (Anonymous, 1981):

crabeater seals	15,000,000
Weddell seals	730,000
leopard seals	220,000
Ross seals	220,000

These seals have never been commercially exploited. It is not known to what extent their numbers vary because of natural causes, but it is believed that crabeater seals have recently been increasing as a result of greater availability of krill (their main food), following the depletion of the large baleen whales.

Fur seals of one or other species (*Arctocephalus gazella* or the slightly more northerly *A. tropicalis* or *A. forsteri*) are found on many of the antarctic and sub-antarctic islands; Marion Island has both *A. gazella* and *A. tropicalis*. Bonner (1982) gives a clear description of the way in which, during the 19th century, the islands and their large seal colonies were discovered; the discovery was rapidly followed by exploitation and depletion of the seal stocks, often close to the point of extinction.

Fortunately, extinction does not seem to have occurred anywhere, and after nearly a century of protection most stocks are recovering. The antarctic fur seals at South Georgia have recently been increasing very rapidly, at a rate of nearly 17% per year (Payne, 1977). This stock is probably approaching its original level of abundance of about one million animals, although its distribution over different breeding sites is not the same as it was previously. Although this rate of increase is exceptional, quite high rates have been observed elsewhere; a rate of 10.5%, for example, has been recorded at Marion Island (Condy, 1978).

The other important sub-antarctic seal is the southern elephant seal. This very large seal – the male may weigh up to three or four tonnes – is found on many of the sub-antarctic islands, with large groups at South Georgia, Kerguelen and Macquarie Islands. Like the fur seals, this species was heavily exploited and depleted in the 19th century, but never to the same extreme extent as the fur seals. After most killing stopped, about the beginning of the 20th century, stocks seem to have recovered. Most appear to be stable at present, though there are indications that the stock at Kerguelen is decreasing (Pascal, 1985). The total numbers probably stand at about 600,000: half at South Georgia, 200,000 at Kerguelen, and 100,000 at Macquarie (Laws, 1960). Pascal (1985) suggests that these figures underestimate the Indian Ocean population, which may consist of about 280,000 animals.

Utilization

When one of the largest colonies of fur seals in the southern hemisphere, that is, the colony on the Juan Fernandez Islands, was first discovered, Dampier (1729), quoted by Bonner (1982), wrote: "Large ships might here load themselves with Seal Skins and Trane-oyl; for they are extraordinarily fat." Nevertheless, the fur seals seem to have been harvested almost exclusively for their skins. In contrast, elephant seals have been killed almost exclusively for their oil.

The meat from southern ocean seals has been little used commercially, but in the so-called "heroic age" of antarctic exploration, at the beginning of this century, seal meat was important as food for men and sledge-dogs. The liver was (and is) particularly appreciated. Scott (1905) noted that, on his first expedition, he and his men were tempted to kill seals for their livers only.

Interaction with Fisheries

The chief food of several species, particularly crabeater seals and fur seals, is krill. The harvesting of krill has recently commenced on a scale which, although large, is still only a fraction of the potential level. While it is logical to expect that the abundance of seals would affect the amount of krill that could be caught, the principal concern has been from the other direction: it focuses on the degree to which harvesting of krill might affect seals and other consumers of krill, particularly baleen whales (May et al., 1979; Mitchell and Sandbrooke, 1980).

There is some indication that fishing has already had an impact on elephant seals, which eat fish and squid. The elephant seal stock around Kerguelen may have decreased lately, possibly in response to the increased catches of fish made there during the last 15 years (Pascal, 1985). The data, however, are not conclusive. In any event, the impact of seals on fish stocks is not an issue in the southern ocean.

Management Policy and Practice

The exploitation of fur seals and elephant seals was unmanaged until early in the 20th century, with predictable results. The fur seals were reduced to near extinction, and the number of elephant seals declined. Since

the elephant seals were less attractive economically, they were not brought to such a low level. In the first decade of this century, in connection with the birth of modern antarctic whaling, the British established effective jurisdiction over South Georgia and extended existing sealing legislation from the Falklands to South Georgia. This move involved setting a licence fee and an annual quota. Later scientific analysis (Laws, 1960) showed that those regulations were not sufficiently effective, and modified regulations were introduced in 1962. These reversed the negative trends in the populations. They would have allowed sealing to continue indefinitely if the whaling industry, to which sealing served as a profitable adjunct, had not collapsed. The antarctic sealing industry ended in 1964 (Bonner, 1982).

For the true antarctic seals, the interested countries, largely the Antarctic Treaty Consultative Powers, have taken the unusual and very positive step of setting up a management mechanism in advance of any commercial harvesting. In 1972, the Convention for the Conservation of Antarctic Seals was signed in London. Under this Convention, precautionary measures, including provisional quotas, have been agreed upon. It seems unlikely, however, that any commercial sealing will develop in the Antarctic in the immediate future, and these arrangements remain untested.

Research

With the upsurge of interest in the Antarctic in recent years, a considerable amount of research has been done on the seals of the southern ocean. This investigation is in addition to research that has been in progress for many years, notably by the British Antarctic Survey, on the fur seals and elephant seals of South Georgia. For the more accessible sub-antarctic seals, the research covers a wide spectrum, and there now exists a good understanding of general biology, distribution and/or numbers, as well as some very detailed information, such as that on depth of diving and feeding behaviour. The seals living on the ice are not so easy to reach, and research on them has been less comprehensive. Though some detailed studies have been made, it is still difficult to obtain an accurate estimate of the total numbers of the seals, and to determine how these numbers may be changing.

South African and Namibian Seals

Stocks

One species of seal, the Cape fur seal (*Arctocephalus pusillus*), is found in the waters off southern Africa in significant numbers, though occasional wanderers from the antarctic and sub-antarctic stocks of seals visit South African waters (Shaughnessy, 1982; from whose work most of the information in this section has been taken). Current (1983) population abundance has been estimated as about 1.2 million fur seals, with an annual pup production of just fewer than 300,000 (Stander, 1985). These seals are spread out over some 20 breeding sites, mainly small islands, along the coast of Namibia and South Africa as far east as Algoa Bay, and they have been commercially exploited since 1610. Although there have been some great reductions in their numbers, the stocks as a whole have not fallen to extremely low levels. The lowest level of abundance was reached at about the end of the 19th century; since then numbers have probably increased about tenfold (Shaughnessy and Best, 1982). Numbers are still probably increasing at a rate of approximately 4% per year, although, as Table 28.1 shows, there are differences among colonies, and the present population is some 50% higher than the estimate given by Shaughnessy (1979) in the report of the Advisory Committee on Marine Resources Research arising from that body's consultation on marine mammals. It is probable that, as a whole, the population is less abundant than it was when commercial exploitation began; Shaughnessy and Best (1982) suggest that the current stock is in the range of 30%–90% of the original population, but some local stocks may be above the original level. Seals now cover the whole of Seal Island in False Bay, whereas when the island was visited in 1687, it also accommodated many gannets (Shaughnessy, 1984).

Utilization

The Cape fur seal has been harvested, principally for its fur, more or less continuously for more than three centuries. Recent annual harvests, until 1982, took about 60,000–80,000 young animals and a small and variable number (2,000–3,000) of bulls. The total take during the whole of the 20th century was 2,390,000 young and 138,000 bulls (Best, 1973; and more recent information from the Sea Fisheries Research Institute). In addition to processing the fur, the sealers extract oil from the blubber of most of the seals killed. The young animals are taken after completion of the first moult, at

Table 28.1
Growth in Cape Fur Seal Population at Southern African Breeding Colonies, 1983

Colony	Estimated Pup Production 1983	Annual Rate of Increase 1971–1983 (%)	Observed Rate of Entanglement[a] 1977	1978	1979
Cape Cross	20,226	1.44	0.56	0.57	0.66
Wolf Bay	33,483	6.69	0.56	0.01	0.01
Atlas Bay	83,663	9.77	0.00	0.00	0.01
Kleinsee	85,697	9.60	0.06	0.01	0.04
Van Reenen Bay	4,355	1.29			
Lions Head	4,647	3.37	–	–	–
Marshall Reef	118	–16.68	–	–	–
Staple Rock	1,396	–8.17	–	0.53	–
Boat Bay Rock	476	–12.49	–	–	–
Dumfudgeon Rock	303	–18.63	–	–	–
Long Island	16,050	1.12	0.00	0.53	0.00
Albatross Rock	6,043	4.63	0.00	0.00	0.00
Sinclair Island	10,829	–3.17	0.02	0.10	0.09
Elephant Rock	1,329	–3.73	–	–	–
Robbesteen	347	–17.80	–	–	–
Seal Island (False Bay)	9,880	–2.53	–	0.22	0.34
Geyser Rock	7,978	6.65	–	0.00	–
Quoin Rock	338	–19.65	–	–	–
Seal Island (Mossel Bay)	222	–23.04	–	–	–
Hollams Bird Island	1,556	–11.04	–	–	–
Black Rock Nam.	391	7.95	–	–	–
Jacobs Reef	3,283	–4.38	–	–	–
Black Rocks S.A.	123	–18.69	–	–	–
Total	292,733				

Source: Stander (1985) and Shaughnessy (1980).

a. In nets and other debris.

any age between six and 10 months (Shaughnessy, 1979). Occasional attempts to use the carcasses for pet food, human consumption or meal production have not been successful.

The composition of the catch changed in 1984, and a greater proportion of bulls is now taken. With the collapse of the European market for seal products, however, the immediate future of the South African sealing industry is bleak. The director of the Sea Fisheries Research Institute notes, in a letter dated 2 January 1985, that "the sale of bull genitalia will probably provide only a short term reprieve before the market becomes saturated" (Stander, 1985).

Several colonies are visited by tourists and Shaughnessy (1979) estimated that, in the 1970s, some 68,000 visitors came to view the seals each year, adding about R70,000 to the local economy. By comparison, the first-hand value of the 1972 harvest amounted to R982,000 (Best, 1973). In 1975, 17,000 people visited Seal Island in Mossel Bay in a five-week period, during which 1,638 young seals were killed. On this occasion hunting and tourism were compatible (Best, 1973).

Interaction with Fisheries

Purse-seines and trawls contain a good supply of available food, and seals take large quantities from the nets, occasionally even following the trawl up the stern ramp of large factory trawlers. Their feeding results in the loss of fish that have already been caught, as well as in damage to nets. No quantitative estimates of the extent of the loss to the fishermen seem to have been made, but that loss is substantial and unarguable. There are also losses to the seal population. Seals get entangled in nets and drown, apparently more often in trawl nets of side-trawlers than in those of stern-trawlers. In 1976, 16 seals were killed in 356 drags by small South African trawlers.

Attempts have been made to scare seals away from nets by using explosives, but they have had limited success. Transmission of killer whale sounds and the use of other devices have not had lasting success (Shaughnessy et al., 1981). Undoubtedly, some fishermen take more direct action with a rifle to protect their catches. Additional mortality probably occurs as a result of entanglement with discarded or lost nets, lines and other objects (Shaughnessy, 1980). The rate of entanglement, based on the estimated percentage of animals observed with objects round their necks, varies

considerably from area to area, but it is in the same general range (between 0.1% and 0.6%) as that observed for northern fur seals. It has been suggested that a recent and otherwise unexplained decline in abundance of seals in the Pribilofs is the result of an additional mortality, especially among juveniles, caused by entanglement. (See Chapters 22 and 23.) It is therefore notable that when the data on entanglement and the rate of increase of abundance of each colony are compared (see Table 28.1), those colonies at which no entanglement was observed were also those with the highest rate of increase.

Another and less direct interaction arises because seals eat the same species of fish as fishermen catch. Cape fur seals feed mainly on fish (about 70% by volume); most of the rest of their food consists of squid. About 1970, the annual consumption was estimated at some 154,000 tonnes (Best, 1973), considerably less than the 2.2 million tonnes taken by fishermen in the southeast Atlantic. Seals seem to be fairly catholic in their tastes, varying their consumption according to the relative abundance of the different species of fish. This is fortunate because of the great changes that have occurred in the stocks of pelagic fish (pilchards, horse mackerel, anchovy), at least partially as a result of fishing (Murphy, 1977; and recent reports of the International Commission for the Southeast Atlantic Fisheries). Though consumption by seals probably has some long-term effect on commercial fish catches, this effect is likely smaller, and certainly less obvious, than the direct effect of taking fish from nets. The divergence in this respect from the situation in Atlantic Canada arises from a difference in the extent in which the seals seek out fishermen's catches, as well as differences in the seals' natural diets and in the dynamics of the fish stocks involved. The effects of fishing on the seals' diet are probably much greater than are the effects of seal predation on commercial fish catches. Seals and humans presumably have an effect, also, on the large populations of birds that feed on the same fish.

Management Policy and Practice

In South Africa and Namibia, fur seals have generally been seen either as a resource to be managed for sustained high harvest or as pests to be kept at a low level. Management policies have been formulated accordingly. There is considerable interest in wildlife in South Africa, but it has focused more on the preservation of species and the natural system as a whole, especially in national parks, with little emphasis on the prevention of all killing. Some seal colonies attract tourists, but compared with some other countries there is little awareness of sealing as an issue and little opposition to the controlled killing of seals.

Legislative authority for current controls exists in the *Sea Birds and Seals Protection Act of 1973*, and in the sealing regulations of 1976. Unlike some other acts or international conventions, these do not make any explicit statement of the measures' objectives, other than that the law provides "for the protection, and the control of the capture and killing, of sea birds and seals." These measures are consistent with controls that have existed since the early 1890s. The management scheme includes concessions to individual companies for exclusive rights to the harvest from specific seal colonies for periods that range from five to 25 years. These concessions encourage the companies concerned to take a responsible long-term interest in the well-being of the seal colony. They are now generally accompanied by explicit quotas on the annual catch.

Research

Active research into the seal stocks of South Africa and Namibia has been carried out for a long time by what is now the Sea Fisheries Research Institute of the Department of Environment Affairs. The location of the marine mammal laboratory has ensured that the work is closely linked with research on fish stocks and the general ecology of the area.

Particular emphasis has been placed on estimating the abundance of fur seals by tagging and direct census from aerial photography. These methods have given consistent results. It appears, from ground-verification studies, that the aerial surveys miss some pups (those between rocks, not yet born or already dead, for instance) and that the aerial counts should be increased by a factor of 1.31 (Rand, 1959, 1972; Best, 1973). Estimates have also been made of the various population parameters and mortality rates, and models have been used to predict the results of different exploitation patterns (Shaughnessy and Best, 1982). These models predict that the maximum yield would be obtained by harvesting about 33% of the female pups reaching the harvesting age (six to ten months) and a rather higher proportion of males. The population would start to decline rapidly at harvesting rates much above 40%–45%.

A significant feature of general ecological research is the instability of the pelagic system, like that of other major upwelling areas of the world, such as Peru and California. Though the immediate cause of the recent collapse of the pilchard stocks off South Africa and Namibia has been overfishing, these stocks are also subject to significant natural fluctuations. It would be reasonable to expect these fluctuations to have some effect on the

seals, despite their ability to change diets. Morrell (1832), for instance, reported finding some half million dead seals on Possession Island. Though this report has been challenged, it is likely that the abundance of seals would not remain precisely constant in the absence of exploitation.

South American Seals

Stocks

Three species of seals are found in South American waters: the South America sea lion, *Otaria flavescens*; the South American fur seal, *Arctocephalus australis*; and the Juan Fernandez fur seal, *A. philippi*. The information on the two former species has been reviewed by Vaz-Ferreira (1982a, 1982b). Both species are distributed widely along the Atlantic and Pacific coasts of the continent, but only in Uruguay are they now being regularly harvested. The Uruguayan seal populations numbered some 30,000 sea lions in 1954 and 250,000 fur seals in 1972. The sea lion population had changed little by the early 1970s. Estimates of population sizes in Uruguay and elsewhere are summarized in Table 28.2.

Table 28.2
South American Seal Population Estimates,[a] 1954–1976[b]

	South American Sea Lion		South American Fur Seal	
Uruguay	30,000	(1972)	250,000	(1972)
Argentina	170,000	(1954)	2,700	(1954)
Falkland Islands	19,000	(1965)	15,000	(1965–66)
Chile[c]	20–25,000	(1965–71)	40,000	(1976)
Peru	13–20,000	(1964–75)	12,000	(1968)

Source: Vaz-Ferreira (1982a, 1982b).

a. Original estimates have been rounded.
b. Approximate dates to which estimates refer are given in parentheses.
c. Excludes southern coast.

Both sea lions and fur seals have varied significantly in abundance, not always in any obvious relation to increases or decreases in the rate of exploitation. The fur seal has been increasing significantly in Uruguay since 1950, even though it has been harvested, while numbers of sea lions on the Falklands decreased greatly between the 1930s and 1965–66, in the absence of any large-scale exploitation.

The Juan Fernandez fur seal is found in the Humboldt current. Perhaps as many as three million were killed in the Juan Fernandez Islands in the 18th century (Bonner, 1982). The species was reduced to very low numbers and was believed by some to be extinct, but now seems to be recovering, though its numbers are still only in the low hundreds (Aguayo, 1979).

Utilization

Europeans have used fur seals and sea lions from the early 16th century for their skins, blubber (oil) and meat. A cargo of fur seals was sent to Seville in 1515, and Drake killed 200 sea lions to provision his crews in 1577. Though at present seals are harvested only in Uruguay, they have been heavily exploited in most parts of their range at one time or another. The sorry history of most of the stocks has been reviewed by Bonner (1982).

In Uruguay, a government agency (*Industrias Loberas y Pesqueras del Estado*) has the sole right to harvest the seals. Current annual kills number some 12,000 fur seals and about 3,000 sea lions, principally males. In addition to the skins, oil is extracted from the blubber at most locations, and on the Isla de Lobos the meat is processed into meal.

Some Uruguayan sea lion colonies attract tourists, and guided tours from nearby Punto del Este visit the rookery at Isla de Lobos daily in the summer. Visits to the fur seal rookeries in the same colony are prohibited, however, to avoid disturbing the animals.

Interaction with Fisheries

Both fur seals and sea lions eat commercial species of fish and squid, which must have some effect on the fisheries catch, though the extent of this effect is unknown. The sea lion, but not the fur seal, is well known for its habit of following fishing vessels and taking fish from nets, as well as causing damage to gear, particularly trammel nets and fishing lines. Again,

no estimate of the extent of the damage is available. While fishing in Uruguay was of relatively minor importance, these losses did not affect the policy relating to seals. With a growing fishing industry, more account may have to be taken of the impact of seals on fishing operations. Fur seals are reported to have been drowned in trammel nets, but there is no information available on the extent of these accidental deaths or on their effect on the dynamics of the seal population.

Management Policy and Practice

Uruguay has a long history of management of seals. As long ago as 1825, Weddell noted the slaughter of seals on the sub-antarctic islands and called for a system of control, particularly to confine the kill to males. He stated:

> *This system is practised at the River of Plata. The Island of Lobos, in the mouth of that river, contains a quantity of seals, and is farmed by the Governor of Monte Video, under certain restrictions, that the hunters shall not take them but at stated periods, in order to prevent animals from being exterminated (Weddell, 1825, cited in Bonner, 1982).*

At the time that Weddell was writing, the Uruguay seal harvest had already been going on for some three centuries, though it is not clear whether harvesting took place in all the intervening years. During the present century, at least, there have been considerable fluctuations in the total catch. The important feature throughout the whole period is that there has been some institution responsible for the seal stocks, with the interest and authority to control the harvest. In the early years this authority was very direct: the Governor of Montevideo had the personal right to the harvest, which gave him a direct interest in maintaining the stock (Bonner, 1982). The actual controls may have been concerned more with ensuring that no unauthorized person took seals than with more sophisticated measures such as catch quotas based on scientific analysis, but they have been effective in maintaining the stocks.

Provision exists for licensing of sealing in Argentina, and for controls of sex and ages of any animals killed in Peru, but there is no current

significant harvesting. In Chile seals are protected, though there may be some poaching there and elsewhere.

Research

While little full-time research has been done by seal specialists, all the countries concerned have carried out research on seals, either in the universities or as part of general fishery studies. Past research has concentrated on the basic biology of the seals. Vaz-Ferreira (1982b) defined the major research needs as the identification of possible stock separation of both sea lions and fur seals, and studies of the population dynamics of sea lions and their interaction with fisheries.

Seals of the United Kingdom

Stocks

Two species of seals are commonly found in U.K. waters; these are the grey seal and the harbour seal (known as the common seal in the United Kingdom). Some northern seals have been found infrequently. Neither of the two species migrates over long distances, and the British stocks are probably, for the most part, independent of the stocks in other countries. Within the United Kingdom the grey seal breeds mainly in a few quite large and apparently independent concentrations such as those of the Farne Islands (which lie off the northeast coast of England), the Orkney Islands and several of the Hebrides Islands. The harbour seal breeds in smaller groups. The general biology of British seals is described in detail by Hewer (1974).

At the beginning of the 20th century, the grey seal was believed to be very scarce; indeed, some people thought that it was "slowly but surely advancing along the road to extinction" because of local killing (Prichard, 1913, quoted in Bonner, 1982; from whose work much of this material is taken). The grey seal was probably never as scarce as was believed. There may have been misidentification of grey seals as harbour seals, particularly because of the vernacular name. Given the more extreme statements about the Canadian harp seal harvest, it is worth repeating Rae's (1960) comment, cited by Bonner (1982), that Prichard's account "set a standard in emotional appeal, in scientific inaccuracy and in illogical reason which appears to have

been followed, doubtless under misapprehension, in subsequent press articles and statements on the grey seal." Both the original appeal and the later reaction to it are echoed in the Canadian situation.

Regulations to protect the grey seal were introduced through the *Grey Seal Protection Act* of 1914. Largely as a result of these measures, but possibly, also, because of depopulation of the outer islands, grey seals have increased. Good estimates of numbers are available only from about 1955. Since then, stocks at several of the main breeding sites, the Farne Islands, Orkney and Hebrides' North Rona, have increased at a rate of some 6%–7% per year (Summers, 1978). Recent data from the National Environment Research Council (NERC, 1984) suggest a population of 84,000 grey seals in 1982. This figure represents over half the total world population of this species.

Less attention has been paid to harbour seals. Minimum population estimates from surveys stand at about 20,500 (NERC, 1984). In two areas, the Wash and the Shetlands, the numbers are believed to be increasing, but in three others, the Inner and Outer Hebrides, and eastern Scotland, the status of the stock is unknown.

While the direct effects of human disturbance, including shooting, have been significant, the less direct effects, such as those arising from pollution, seem to be of little significance to British seal stocks. This situation stands in contrast to that in Dutch waters and in the Baltic, where seal stocks have seriously declined, and where high concentrations of pollutants have been found (Summers et al., 1978).

Utilization

There has never been large-scale commercial hunting of British seals. Subsistence hunting of grey seals, especially off western Scotland, probably dates back to prehistoric times. The Venerable Bede, writing in A.D. 731, noted that "Britain is abounding in fish . . . while seals, dolphins and sometimes whales are caught" (Bede, 1968), and Bonner (1982) quotes 16th century descriptions of sealing in the Orkneys and the Farne Islands. Subsistence hunting at Haskeir in the Hebrides aroused Prichard's anger in 1911, and it was probably responsible for keeping the seal stocks at the level from which they are now increasing. This hunting has been stopped.

Until recently, there was a small-scale commercial hunt for both harbour and grey seals. Excessive catches in the 1960s were believed to have

caused the decline of some harbour seal stocks. Since the 1970 *Conservation of Seals Act*, which bans sealing during the breeding season (1 June to 31 August) except under licence, catches of harbour seals have fallen from a peak of some 1,500 in the late 1960s to zero. Catches of grey seals in the 1970s numbered between 1,000 and 2,000 (Summers, 1979). While skin prices remained high, these activities were economically rewarding. Even during peak times, however, they employed few people, and the loss of the industry has caused no significant economic problem.

Interaction with Fisheries

Three forms of interaction with the fisheries occur: damage to fishing gear and removal of fish from nets, consumption of commercially valuable fish, and transmission of nematode parasites which causes a loss in the value of the catch. There is little doubt that all three forms occur, but as in Canada, there is considerable scientific argument about the extent of the effects, especially about the degree of competition between man and seals for different species of fish.

Little information is available on the extent of incidental kills of seals in fishing gear. Until recently, this mortality has probably been very minor, although there may have been some increase with the more extensive use of bottom-set gill nets.

The effects on salmon and salmon fishing have attracted special attention (Rae and Shearer, 1965). (See also Chapter 25.) These are more apparent and possibly more important than those on other species of fish. Further, salmon seem to hold a special status among fish, comparable to that held by seals and seal-related activities among other conservation issues. The widespread public concern derives partly from the fact that many salmon anglers and their friends occupy positions at the upper political and administrative levels. There has also been considerable concern about the decline in the numbers of fish, especially the larger fish (i.e., "salmon" as compared to grilse), returning to British rivers. The cause of this reduction is unknown. Increased numbers of seals are among the suspects, together with increased gill-netting in English coastal waters and heavy fishing off Greenland and on the high seas.

Damage to gear and catch is highly visible to fishermen. While the total impact (measured by the percentage of damaged fish entering the wholesale market) may be small, and while the extent of damage to nets has

decreased since the introduction of synthetic nets (Parrish and Shearer, 1977), the problem of seal damage is nonetheless real to salmon fishermen in some locations. Recent analysis (NERC, 1984) shows no clear evidence of increased damage corresponding to the recent increases in the numbers of the main culprits, the grey seals. Factors other than the overall abundance of seals may be more important. Thus, reducing abundance within the limits generally acceptable to the public may be less effective than other measures, such as firing rifles to frighten seals away.

More doubt surrounds the effects of the consumption by seals of commercial fish catches. Early studies of feeding were based on the stomachs of seals, many shot near salmon nets. These studies suggested that seals consumed large quantities of salmon. Since the fish were taken just as they were entering the main fishery, seal predation would have had a serious impact on the fisheries (Rae, 1968, 1973). More recent studies (NERC, 1984) show no traces of salmon in the faeces of seals. Rather, the most significant element in most areas consists of traces of sand lance, and there is evidence that various commercial demersal species make up most of the remainder of the food consumed (NERC, 1985, Table 9.3). The NERC studies also failed to find any relationship between the survival of salmon in the sea and the increased abundance of grey seals. There is, however, no proof that such a relationship does not exist. Undoubtedly, some seals eat some salmon at some times, but it is still not clear whether (apart from those removed from nets) they eat enough to cause a significant loss to the salmon fishery or to individual salmon fishermen.

There is less dispute over the impact on fisheries for other species. The 1984 NERC report estimated that seals consume a total volume of some 140,000 tonnes of fish annually. More than half of this amount consists of sand lance and other low-valued species used for fish meal, but nearly 40,000 tonnes were composed of ling, cod and other valuable species. Further studies on the energetics of seals and the species eaten by them may modify this total. The losses to fishermen could be significantly more, or less, than the total consumption by seals, depending on the sizes of fish eaten by seals and the dynamics of each fish species. The impact in absolute terms is substantial, probably representing a loss of millions, or even tens of millions, of pounds annually. However, as a percentage of the total value of the catch and as a percentage of the catch of any one individual fisherman, the impact, except possibly that relating to sand lance and ling, is small. It is reasonable to assume that this impact is roughly proportional to the total abundance of seals, but the truth of this assumption has not been demonstrated.

Similar comments apply to *Pseudoterranova decipiens*. Infection of fish flesh by this nematode causes losses to the processing industry, and those losses may be increasing, but the extent of the loss as a percentage of the total turnover, is not serious at present. Moreover, it has not been publicized because of the possible impact on sales.

Management Policy and Practice

The 1914 legislation was intended to protect grey seals from what was seen as a threat to their existence as a species. The 1970 Act widened the scope of legislation to consider seals as a possible resource or as a threat to fisheries. Killing of seals can be licensed to prevent damage to fisheries, to use a "population surplus" as a resource, or to reduce "a population surplus of seals for management purposes" (*Conservation of Seals Act*, 1970, section 10c). What is meant by a "surplus" or by "management purposes" is not defined, nor is there any requirement for management to aim at some specified level, such as that giving maximum sustainable yield.

Management authorities, that is, the Department of Agriculture and Fisheries for Scotland and the Home Office in England, advised by the National Environment Research Council, have a wide choice of objectives which should be capable of being matched to current public opinion. Nevertheless, management has not been easy.

One problem occurred on the Farne Islands, where the increasing abundance of grey seals was causing crowding and a high mortality rate of up to 25% among pups (Bonner and Hickling, 1971). This increase was also causing physical damage to the vegetation and loss of soil, thus destroying the nesting sites of puffins and gulls. These effects were judged to be undesirable. The management authority interpreting "management purposes" to include attempts to control these ecological effects, issued licences to kill seals. Over 1,000 seals, split roughly between pups and adults, were killed in 1972 and in 1975; and rather fewer were killed in 1977 (Summers, 1979, Table 8). After 1978, the policy was changed to one of active disturbance of seals at the overcrowded colonies. This intervention seems to have had most of the desired effects. After peaking at over 8,000 in 1979, the total number of seals has remained between 7,000 and 8,000. Shooting noises and other disturbances have caused the seals to disperse more uniformly over the islands, with less damage to vegetation, though pup mortality remains high. The killings on the Farne Islands, a nature reserve owned by the National Trust, reawakened public opposition which had previously caused the cessation, in 1965, of culls aimed at reducing damage to fisheries.

However, the National Trust has been able to explain the purpose of the culls, and since the number of animals killed has been reduced as the population growth ceased, the protest has remained within bounds. Much less success attended the 1977 attempt to extend the existing annual kill of 1,500 pups in the Orkneys and Outer Hebrides to adults, in order to reverse the increasing population trend and to stabilize the numbers at mid-1960s levels. This kill was to be carried out by Norwegian sealers under contract to the Scottish Office, but the plan came under very heavy attack. The background of the attack was undoubtedly the general opposition to any killing of seals, and especially to the idea that governments should actively promote increased killing. The attack was based on doubts about the scientific evidence, especially concerning the amounts of fish consumed by seals, and about the impact of this consumption on commercial fisheries. After a season in 1977 which was hampered by bad weather and by on-site protests conducted by Greenpeace and other groups, and after opposing motions had been made in the European Parliament and at the IUCN conference at Ashkhabad, U.S.S.R., in October of that year, further actions to implement the kill were abandoned. The cancellation of the proposed kill was front-page news in all the U.K. papers.

The Orkney seal kill has much in common with the Canadian harp seal story. There was enormous public interest coupled with a lack of public knowledge about the details of the subject. There was confusion between the real basis of much of the public opposition, that is, any killing of seals as a matter of principle, and the apparent issue, that is, the reliability of the scientific evidence. Both situations were coloured by what, in hindsight at least, appears to be ground for serious concern: that the management authority was a fisheries-dominated department. Thus, in a conflict between those wishing to kill seals (for direct use, or to protect fisheries) and those wishing to protect seals, the same institution was both the judge and the chief spokesman for one of the adversaries. The advantages and disadvantages of including the seal-management authority in a fisheries-dominated agency are discussed in Chapter 30.

Research

Government-sponsored seal research is carried out in the United Kingdom by the Sea Mammal Research Unit (SMRU), which is part of the National Environment Research Council. Unlike those in most other countries, this research unit is independent of government-sponsored research into fisheries, which is carried out in laboratories attached to the fisheries

departments for England and Wales, and for Scotland. The SMRU is only weakly linked, through the NERC structure, with other marine research. Against the possible disadvantage of lack of close co-ordination, the SMRU has the advantage of being physically located with the British Antarctic Survey, which has a strong tradition of research into whales and seals of the southern oceans and their associated ecosystems.

British research into seals has been extensive and of high quality. Some of it, such as the modelling of seal populations to determine policies which would quickly bring populations to some desired stable level, is immediately relevant to Canadian problems. Nevertheless, the scientific results have not, at least in respect of the proposed Scottish grey seal cull, settled the issue of whether adult grey seals should be killed. Thus the differences between earlier studies and most recent NERC reports, which indicate a much lower consumption of salmon, are seen by some conservation groups to discredit previous proposals for a cull. This view is reflected in the headline "Grey seals versus fisheries: case dismissed?" in *RSPCA Today* (Autumn-Winter, 1984). In fact, the discrepancies are not greatly significant in relation to the question at issue. The interaction of seals with salmon is still an open question; the new report indicates a substantial cash loss to demersal fisheries such as ling and cod. A simple economic comparison between the costs of killing seals and the resulting benefits to fisheries yields the same results whatever set of figures is used to calculate the benefits. The benefits to fishermen are greater than the economic costs of killing seals. The important question, however, is whether some economic benefit to some fishermen justifies killing seals. This question is not easy to answer. Estimates of damage done to fisheries by seals indicate that a kill would yield some benefits to fishermen, but not enough to make the difference between bankruptcy and reasonable profit. The precise value of the benefits makes little difference to the answer. Unfortunately, this last question has not often been publicly addressed, either in the United Kingdom or, to date, in Canada, and there is certainly no answer generally acceptable to the public.

Norwegian Seals

The information in this section has been taken from the brief presented by Øritsland (1985), except where otherwise stated.

Stocks

Six species of seal are found in Norwegian waters, including Svalbard and Jan Mayen. Four species are northern animals: the bearded, the ringed, the harp and the hooded seal. They have not usually been found in significant numbers along the continental coast of Norway, although large numbers of harp seals have recently entered the waters along the Finnmark coast. The other two species, grey and harbour seals, are more southern species and are found along the continental coast; there is a small number of harbour seals in Svalbard.

Norway is the only country that has operated a significant long-distance sealing industry during the present century. This industry has been primarily focused on the harp and hooded seals of the northwest Atlantic, and these stocks are treated at length in other parts of this Report. The Norwegians have shown some interest in antarctic seals. A trial voyage was made to the Antarctic in August–October, 1964, and the participants took 852 seals (Øritsland, 1977), but the economics did not seem promising and no further commercial activity has taken place there.

The main commercial Norwegian sealing has been directed at harp and hooded seals. The trends in the three stocks concerned in the east Atlantic – the White Sea (East Ice) and Jan Mayen Island (West Ice) herds of harp seals and the hooded seals on the West Ice – have been very similar in the past half century to those in the west Atlantic. The same techniques such as marking, surveys and age-composition analysis have been used to estimate abundance and to monitor the status of the populations.

For harp seals, these estimates suggest pup productions of about 200,000 and 50,000 at the East Ice and West Ice respectively; these figures correspond to a total east Atlantic population of about one million. The current pup production of hooded seals on the West Ice is believed to be about 50,000 (Jacobsen, 1984), corresponding to a total population of a little less than a quarter million.

Similar doubts surround these estimates and the corresponding figures for the west Atlantic. Because of the greater public attention paid to the Canadian seal hunt, the data base for the west Atlantic is probably better and has certainly been more carefully analysed than that for the eastern Atlantic so that greater doubts surround the eastern figures. Probably the best that can be said of these latter figures is that they provide a fair representation of the order of magnitude of the current population sizes.

Even greater difficulties surround an evaluation of the recent trends in abundance. It seems fairly clear that the abundance of both harp and hooded seals in the east Atlantic decreased significantly in the 1950s and 1960s. Various measures were then introduced, both unilaterally and through joint action by the U.S.S.R. and Norway. These include protection of adult seals, especially breeding females, and limits on the total catch of pups. Observers directly concerned believe that these measures have resulted in a reversal of the decreasing trend. For example, results of Soviet surveys, quoted by Øritsland (1985), indicated an annual rate of increase of 5% in White Sea harp seals between 1968 and 1976. Others, however, have stressed the uncertainties, and found that it can be concluded with certainty only that the earlier decrease has slowed down (e.g. NCC, 1982). On balance, it seems probable that recent harvests have been below the sustainable yield, though the effects of the recent large incidental kill of harp seals in gill nets in the Finnmark region should be taken into account.

Neither of the other two species of northern seals has been subject to a specialized hunt, though both have been caught incidentally, particularly bearded seals in connection with a polar bear hunt in the Svalbard area. This may have reduced the stocks of bearded seals; however, the polar bear hunt has ceased and the seals now appear to be increasing. There is little evidence of any significant change in ringed seal stocks.

While the two southern seals have not been subject to large-scale commercial hunting, they have probably been subject to local hunting, especially by fishermen. By the early 20th century, the grey seal, which seems more vulnerable to hunting and disturbance than some other species, was, as in most other parts of its range and for similar reasons, at a low level. Recently both species have been fully protected in southern Norway, and a closed season has been declared for harbour seals in northern Norway, from 1 May to 30 November. These measures seem effective and both species seem to be increasing, at rates of up to 13% per year in some grey seal colonies. Total numbers are still relatively small, however, with estimated total Norwegian populations of 7,000 grey seals and 8,000 harbour seals. Nevertheless, the increases have been sufficient to cause concern among fishermen, and a culling program has been introduced for both species. The effect of this program is not yet clear.

Utilization

Norway has one of the world's largest sealing industries. Because, like Canadian sealing, it is concentrated in a few places, it has a local impor-

tance greater than its small contribution to the overall Norwegian economy. The shrinkage of the industry, first because of the need to conserve stocks and secondly because of the loss of markets, has caused severe economic problems. These problems and the measures, such as subsidies, taken by the Norwegian government to counteract them are relevant to the problems of the Canadian sealing industry and possible remedial measures; for these reasons they are treated at length in Chapter 19.

Interaction with Fisheries

All the interactions which raise actual or potential problems in Canada also occur in Norway. Seals damage nets, remove fish from them, are carriers of the nematode *P. decipiens*, and are major predators on some species of commercial fish. Some concern, though minor, has also been expressed about the effect of commercial fishing on the availability of food for seals. As in Canada, there are few doubts that such effects exist, but it is difficult to quantify them.

Until recently, these effects may have been a nuisance to the fishermen concerned, but they did not appear to be serious. However, in 1978 and in subsequent years, large numbers of harp seals have appeared along the Finnmark coast in the early months of the year. This change in migration pattern may have resulted from changes in the stocks of capelin, one of the major foods of harp seals and itself the subject of an intensive fishery. The influx of seals occurs early in the year, at the same time as the important gill-net fishery for cod. Many seals become entangled in the nets, and there is evidence that up to 10,000 seals have been drowned in some seasons (Bjørge et al., 1981; see Chapter 23). The cost in damage to gear has been estimated at 0.5 to 1.0 million Nkr, with losses of a similar magnitude attributed to reduction in catches.

Apart from this recent situation, the seals most involved in direct effects on the fisheries have been grey seals, which cause damage to gear, especially traps, and transmit parasites, and harbour seals which cause damage to gear.

Management Policy and Practice

Norwegian policy towards seals has been based on the view that seals, like fish, are a renewable resource to be used responsibly. This seems consistent with the majority view of Norwegians. (See Chapter 11, which

details the results of the Gallup Poll conducted for the Royal Commission.) Responsibility for the management of sealing is established by the *Seals and Sealing Act* of 14 December, 1951, administered by the Royal Norwegian Ministry of Fisheries. The Norwegian Sealing Council, in which scientists, the sealing industry and various ministries participate, advises the ministry.

Because the major commercial hunts used to take place in international waters, and other countries harvested the same stocks of harp and hooded seals, Norway has made agreements with the countries concerned. The agreements made with Canada, bilaterally and under the International Commission for the Northwest Atlantic Fisheries (ICNAF) and its successor, the Northwest Atlantic Fisheries Organization (NAFO), concerning the west Atlantic stocks, are described later in this chapter. Norway and the U.S.S.R. concluded a bilateral agreement in 1957, in respect of the east Atlantic, but discussions on seals are now included in the annual discussions on fisheries conducted by the joint Norwegian-Soviet Fisheries Commission established in 1983. Regular consultations with Denmark and Greenland about sealing in the Greenland Sea were initiated in 1984. The International Council for the Exploration of the Sea (ICES) has established a working party to review the scientific information on the state of harp and hooded seal stocks.

The regulations and their impact on the stocks of the west Atlantic harp and hooded seals are described in detail in Chapters 21 and 30. Quotas have been set for the harp seals of the White Sea stock since 1965, and for the harp and hooded seals of the West Ice since 1971. The catches vary from year to year because of changes in ice conditions, and in many years they have been well below the quotas, which serve principally to put a ceiling on the catches in unusually favourable years. Although the quotas have been set at about the level of the central estimate of sustainable yield, they seem to have allowed the stocks to increase, and recently there has been some increase in quotas. The reversal of the decreasing trend observed in the period up to 1965 was also helped by the protection of breeding adults; this protection has applied to harp seals on the East Ice since 1963, to those on the West Ice since 1965 and to female hooded seals (except for compelling safety reasons) since 1969.

Until very recently, the major factor in determining Norwegian sealing policy has been the long-term economic interest of the sealing industry and of the local communities for which sealing has been important. This interest has been the chief justification for the quotas and other management measures and for the economic support given to the industry to counteract the current slump in the market. (See Chapter 19.) Some concern has

been given to the well-being of the seals and this has been reflected in regulations governing the use of the hakapik and other killing methods. (See Chapter 20.) However, neither the general conservation movement nor the effect of seals on fisheries has had a major influence on Norwegian sealing policy. This situation probably will change in the future, in the wake of a sustained slump in the market for seal products and an increase in the apparent impact of seals on fisheries.

Comparisons among Regions

Population Dynamics

Experiences in these other areas all tend to confirm the theories of the dynamics of seal stocks and their response to exploitation, which are the basis for assessments such as the sustainable yield. On the negative side, there are several examples of the devastating effects of uncontrolled exploitation. Where the seals were concentrated on a few small islands and there were no marketing or other constraints on the number of seals that could be killed, as was the case with several sub-antarctic fur seal stocks, it could take only a few years from the time of discovery to the time when the stock had been reduced very nearly to extinction. Fortunately, it seems difficult to exterminate a seal species completely by over-exploitation, and despite near misses these fur seal species survived.

The most seriously threatened species today are the monk seals, and the Caribbean monk seal is probably extinct. Monk seals live in warm waters outside the main areas of seal distribution. Although they have been and may continue to be killed, by fishermen for example, they are not now subject to direct hunting. The threats to them seem to come from changes in habitat and general human disturbance, to which they appear more vulnerable than other species.

Depleted populations of seals can show remarkable resilience. For example, the antarctic fur seal stock at South Georgia virtually disappeared as a result of intense exploitation in the 19th century. For the last 30 years, however, the population has doubled every five years, and it now numbers over a million. This extremely rapid growth rate has been said to be the result of the increased availability of krill, thanks to the depletion of the stocks of large baleen whales. This may be part of the reason but the basic constraints that limit the potential growth rate of any seal population

still apply. Although only one pup is born each year and sexual maturity is not attained for several years, very rapid growth has been achieved.

The other notable feature of the fur seals at South Georgia is that it seems, though there are too few observations in the relevant period to be sure, that the depleted stock remained for a long time at a very low level, increasing only slowly if at all, before increasing rapidly in the middle of the present century. Conservationists are concerned that this pattern may indicate the existence of a lower limit in the population below which recovery is difficult and may not occur at all. If there is such a limit, it must be very low indeed.

Apart from the dramatic story of the collapse and later recovery of the southern fur seals, there are less extreme experiences showing the ability of seal stocks, under proper conditions, to sustain substantial harvests over long periods. In addition to the traditional subsistence hunts by aboriginal peoples of the Arctic, a commercial hunt for seals in Uruguay has been carried on for four centuries. The northern fur seal at the Pribilofs and the southern elephant seal at South Georgia both recovered from depletion and then were harvested at close to a sustained level for many years.

The last two stocks also demonstrate the need for careful monitoring as exploitation proceeds and the need to adjust management practices as new information becomes available. On the Pribilofs, for example, it was discovered that certain details of population-dynamics theories were incorrect; the population could not sustain as great a harvest of females as had been thought. At South Georgia, the original analyses proved too simplistic and studies of age and maturity showed the need for reducing catches somewhat.

A note of caution is in order concerning the extent to which a seal population can be reduced without jeopardizing its genetic variability. There are two cases in the north Pacific that exemplify this concern. The Guadalupe fur seal was once abundant on the islands of northern Baja California and southern California. It was nearly exterminated by sealing during the 19th century. A few survivors were discovered on Guadalupe in 1954 (Hubbs, 1956), and the population had recovered to more than 500 by the 1970s (Hubbs, 1979). Although large rookeries are known to have existed on open beaches prior to intensive exploitation, the individuals that survived to contribute to the species' recovery had the habit of pupping in caves. Peterson et al. (1968) noted that:

> *It is possible that during the rapid wholesale slaughter of the fur seals a century ago those animals in open rookeries were selectively eliminated. Only a nucleus with secretive behavioral traits may have persisted, thereby modifying the behavior of the surviving population.*

The northern elephant seal was similarly driven to near-extinction by uncontrolled hunting; there may have been as few as 20 individuals surviving by the early 1890s (Bartholomew, 1952). The population has recovered well, reoccupying its former breeding range and numbering in the tens of thousands today. Biochemical studies suggest, however, that the species has lost a pool of genetic variability with which to adapt to changing conditions, making it "especially vulnerable to environmental modification" (Bonnell and Selander, 1974). These concerns about genetic variability relate to populations which probably fell below 100 individuals and do not seem to be applicable to any Canadian seal population (apart from the northern elephant seal which is an infrequent visitor to Canadian waters).

Interactions with Fisheries

All seals eat fish and other marine animals, many of which are harvested or potentially harvestable by humans. Most seals are intelligent enough to recognize that fish caught in nets or on hooks are an easier source of food than are fish swimming in the open sea. Some conflict between seals and fisheries is therefore inevitable.

Complaints from fishermen about the food eaten by seals and the effect that seals' predation may be having on their catches are rare. In part, this may be because exploitation of seals usually precedes or occurs in parallel with exploitation of fish. By the time that fishermen become concerned about declining fish catches, the seal stocks may have been so depleted that competition does not arise as a serious issue. It can, however, become an issue when seal stocks recover and fish stocks do not, often because of continued intensive fishing. This seems to have occurred in the United Kingdom, which is the area outside Canada in which complaints about competition are most obviously a serious issue. The intensity of some of these complaints may be a misleading indication of the real concern of fishermen about competition. Partly, these complaints derive from much stronger complaints about removal of fish, especially salmon, from nets and partly, they are based on biased estimates of the proportion of salmon and other valuable fish in the diet of seals.

The most forceful complaints arise when the fishermen can see the seals taking fish from their nets or when the seals damage their nets. Problems of this nature in some other countries are at least as severe as those in Canada. The Cape fur seal of southern Africa seems to be particularly aggressive in taking fish, often leaping in large numbers into purse-seines to take sardines or anchovies. When attempting to take hake or other fish from trawl-nets, they may even go up the stern ramp of a trawler, either deliberately or because they are entangled in the net. A frightened and angry 500-kilogram male fur seal is not a welcome visitor on the limited space of the deck of a fishing vessel, even a large factory trawler.

Yet, despite the obvious impact of seals on fisheries, the complaints by fishermen rarely contribute to the sort of crisis that has been experienced in Canada in respect of the harp seal harvest. The controversy over the culling of grey seals in the United Kingdom has attracted much notice, but it arose because of public opposition to actions by the government, rather than because of the fishermen's efforts to force an unwilling government to act.

It is likely that complaints by fishermen are generally muted because many of the seal stocks potentially concerned have been depleted or kept in check by past or current harvesting. In addition, most fishermen accept seals as part of their environment, together with bad weather, excessive catches by other fishermen and poor markets. Fishermen complain about these problems without much expectation that the situation will improve.

Many seal stocks are now increasing because of improved management or outright protection; these include grey seals in the United Kingdom, fur seals in southern Africa and several species in the United States. When fishermen experience the effects of increased seal numbers on the fisheries, they may well expect governments to act on their behalf. If the governments are not sufficiently responsive to these concerns, the pressure of protests from fishermen may grow.

Public Concerns

Outside of Canada, the only countries where there appears to be much concern over the killing of seals in national waters are the United Kingdom and the United States. In other countries with significant sealing (Greenland, Norway, South Africa, Uruguay, the U.S.S.R.), sealing seems to be viewed by the public as merely another legitimate use of national living resources and one that arouses little public interest.

In the United States, public concern with seals is bound up with a wider concern for marine mammals in general. Much of this concern has been focused on the depletion of large whales, the very large incidental catches of porpoises in tuna purse-seines during the 1960s and 1970s, and the Canadian whitecoat (harp seal) harvest. Some environmental groups have taken an interest in the Pribilof fur seal harvest but this issue does not seem to have aroused much public interest. Fishermen appear to be the only major group with an outspoken interest in the seal stocks in the lower 48 states. Sealing or the killing of seals as a control measure is not seen as an important domestic issue in the United States. In the Gallup poll carried out for the Royal Commission, 30% of Americans interviewed identified the United States as being involved in sealing, compared with 75% of Canadians and 83% of Norwegians who identified their own national involvement. (See Chapter 11.)

In the United Kingdom, the main public concern is with the culling of grey seals, either as a measure to limit the ecological consequences of overcrowding on the Farne Islands or to reduce competition with fisheries. As with the harp seal protests, it is useful to distinguish between those opposed to any killing of seals, and especially the killing of pups, and those concerned that the scientific basis for the cull has not been sufficiently well established. Together, these two groups have been able to raise public awareness and public concern to a very high level.

The objections of the second group may be met by better research and, particularly, a better presentation of the results of research and the implication of uncertainties that inevitably surround the results of any research. Although the objections of the first group cannot easily be met by argument, they require accommodation in the development of a national policy with respect to seals and sealing that is designed to reconcile the divergent interests and views on the matter.

Management Policy

Countries differ in their approaches to seal management. In most countries where seals are common, they are, as in Canada, included among fish and other marine living resources as part of the responsibilities of the Department of Fisheries or the equivalent branch of government. In contrast, in the United States, seals together with other marine mammals, enjoy a rather special status under the *Marine Mammal Protection Act of 1972*. For seals there, ultimate responsibility still lies with the department that

includes the National Oceanic and Atmospheric Administration, which handles normal marine fishery matters, but the immediate responsibility lies with a special Marine Mammal Commission whose main concern, judged by the fields of responsibility of those who nominate commissioners, is with scientific and environmental or ecological matters rather than with the use of a resource.

In the United Kingdom, responsibilities are divided. In Scotland, policy, such as that on culling, has lain with the Department of Agriculture and Fisheries for Scotland (DAFS), while in England the lead authority is the Department of Environment rather than that of Agriculture, Fisheries and Food. In both parts of the nation, the lead responsibility for research lies with the Sea Mammal Research Unit, which is part of the National Environment Research Council and quite separate from the fisheries research laboratories.

The political decision as to the locus of responsibility for sealing management is no longer straightforward. To the extent that seals are viewed as more than a harvestable natural resource, the approach to management of a fishery-oriented administrative authority may be out of tune with public opinion. This happened in Scotland. On the basis of available evidence and with a view to protecting the fisheries, DAFS made a reasonable decision to cull grey seals in the Orkneys. The result was an extremely vocal protest from members of the public who viewed seals as special animals and who, in consequence, demanded a higher level of scientific proof that the cull was necessary. Because the department responsible for seals was also responsible for fisheries, which accounted for much more of its day-to-day work than did seals, conservation groups believed that its decisions were necessarily biased toward narrow fishery interests. The converse can be true when seals are handled by a different department. In areas of the United States where seals are increasing in numbers, many fishermen believe that present arrangements are biased in favour of the seals and of those who wish to protect them.

On the other hand, a close link between fisheries and other marine agencies has definite advantages. For example, the close integration among scientific groups (fishery biologists, seal scientists and, often, oceanographers) studying subjects which are part of, or relate to, the same ecosystem should make for more effective research. So long as the public accepts the proposition that seals may be treated as a harvestable, renewable resource, integration of responsibility for seals and fish is desirable. It should lead to a consistent policy for the utilization of each resource and facilitate the resolution of inter-resource conflict.

Canada's International Commitments

Under a number of international agreements and conventions, Canada has assumed certain rights and responsibilities in relation to seals. These include: agreements wholly concerned with seals and sealing, namely, the North Pacific Fur Seal Commission and the Canada/Norway Sealing Commission; fishery commissions in which seals are treated as one of a number of resources, namely, the International Commission for the Northwest Atlantic Fisheries (ICNAF) and its successor, the Northwest Atlantic Fisheries Organization (NAFO); and conservation agreements in which seals are treated among many other species requiring conservation and protection, namely, the Convention on International Trade in Endangered Species (CITES).

North Pacific Fur Seal Commission

The first international agreement to manage and conserve the north Pacific fur seals (specifically the stocks of the northern fur seal, *Callorhinus ursinus*) was signed by Japan, Russia, the United Kingdom (on behalf of Canada) and the United States in 1911. It was one of the first and, on the whole, one of the most successful international agreements for the rational use of marine living resources. The history of the fur seal stocks, including their collapse and recovery under management, is set out in Chapter 22.

Fur seals breed on a number of Soviet islands (Commander and others) and U.S. islands (Pribilofs) in the Bering Sea and northwest Pacific and have a long history of exploitation. At the beginning of this century they were harvested on these islands by Russian and American nationals and on the open seas by sealers from all four signatory countries. International co-operation was therefore needed to manage the resource. This was achieved under the 1911 convention which restricted harvesting, which has involved almost entirely the taking of young sub-adult males, to the breeding islands. Canada and Japan agreed to abstain from high-seas (pelagic) sealing and in return were guaranteed a share of the proceeds from skins taken on the breeding islands.

This agreement enabled the stocks to rebuild, and it was renewed regularly with some differences in form. It was not renewed in 1984, however, and the North Pacific Fur Seal Commission has consequently been terminated. As long as fur seals were regarded as a harvestable resource and it was possible that in the absence of an international management body

pelagic sealing might be revived, Canadian participation in the Commission was fully justified. With the termination of the Commission, and with the changes that have occurred in public attitudes and in the present-day economic realities of sealing, it is now appropriate for Canada to re-examine the forms of collaboration with other countries in relation to the fur seal herds.

Certain groups in the United States which oppose any killing of seals mounted attacks on the North Pacific Fur Seal Commission's existence, which have led to the failure by the United States to renew the Commission's mandate. The groups contend that its chief function was to arrange the orderly killing of several thousand seals every year. The traditional argument that, without the Commission, the seals would be in worse danger from uncontrolled pelagic sealing is no longer as convincing as it once was. There are, however, other problems concerning fur seals which require concerted international action. Entanglement in discarded fishing nets and other debris has come to be recognized as a serious threat to the fur seal population. (See Chapters 22, 23.) Heavy fishing of walleye pollock and other important prey species in the Bering Sea and the Gulf of Alaska may be affecting the fur seals' food supply. At the same time, the large quantities of fish eaten by fur seals and other marine mammals could affect the yield of commercial fisheries.

These problems cannot be tackled effectively by a body concerned solely with seals. In the north Atlantic there is a single scientific body, the International Council for the Exploration of the Sea (ICES), in which all countries bordering on the north Atlantic that are interested in marine research participate and which provides advice on a number of matters, including fisheries management and marine pollution. Such a body in the north Pacific would be in a good position to bring together all the scientific information relating to the fur seals, as well as other marine mammals, and their interactions with fisheries and, to the extent that these interactions are causing problems, it could provide advice on how to deal with these problems. Canada might wish to take action to establish something equivalent to ICES in the north Pacific. Pending progress along these lines, Canada should work at an international level to ensure that effective management of fur seals is maintained. (See Chapter 22.)

Canada/Norway Sealing Commission

This Commission was established under an agreement made between the governments of Canada and Norway in July 1971. Its objectives are to promote co-operation between the two countries in many aspects of seals and sealing, including research, humane killing and conservation of the stocks. The Commission provided a mechanism to permit some continuation of Norwegian sealing on traditional sealing grounds after 1977, when Canada established its 200-mile fishing zone. Though the Commission may make suggestions, it does not have the power to make formal and binding recommendations on the levels of total allowable catch. It originally dealt only with harp seals, but in 1975 the agreement was amended to allow it to deal with hooded seals, bearded seals and walruses.

Despite what appears to be considerable overlap and duplication with ICNAF/NAFO, the Commission played a useful role in the 14 meetings held between 1973 and 1982. It allowed for a broad exchange of views and information outside the framework of ICNAF/NAFO and thus facilitated the making of formal recommendations in the larger multilateral forum. No Norwegian sealing has taken place in the northwest Atlantic since 1982. Because of the depressed market for seal products, there is no immediate prospect of the Norwegians wishing to resume sealing. If they did, it is doubtful that such sealing in the waters under Canadian jurisdiction would be readily acceptable to Canadian public opinion. There may be little for the Commission to do in future. It has not met since an informal meeting was held in January 1983, and it may be best to allow it to die quietly.

International Commission for the Northwest Atlantic Fisheries and the Northwest Atlantic Fisheries Organization

Established in 1949, the International Commission for the Northwest Atlantic Fisheries (ICNAF) was, until the recent changes in the Law of the Sea and the extension of national jurisdictions, one of the typical and also one of the more active regional fisheries commissions. It had broad responsibilities for all fish resources in the region from New England north to the Canadian Arctic and east to Cape Farewell, Greenland. These responsibilities included the compilation of statistics, the promotion and co-ordination of research and the recommendation of management measures. In 1961, it was agreed, on a proposal by the Canadian government, that seals should be included within the responsibilities of ICNAF. This agreement came into force in 1966, when all member countries had ratified it, and a special group,

Panel A, was created to consider seals. This panel, like others, discussed the results of the scientific analyses and advice produced by the Standing Committee on Research and Statistics (STACRES) and made proposals for regulatory measures such as closed seasons and levels of total allowable catch.

The arrangements for scientific work within STACRES ran smoothly and were widely recognized as an effective example of international collaboration. There was dissatisfaction, however, especially on the part of the coastal states, with the performance by ICNAF and similar bodies in implementing effective management measures. Decisions had to be reached by consensus. Thus, proposed measures were often seriously weakened before all members found them acceptable, and management actions were taken too late. Though mesh regulations introduced by ICNAF produced some benefits, they failed on the whole to address urgent problems of overexploitation in the 1960s and 1970s.

Disenchantment with regional fisheries commissions was one factor leading to the massive re-examination of the international Law of the Sea and eventually to the United Nations Conference on the Law of the Sea. Though the Convention codifying the conclusions of the conference has recently been signed, it has not received enough ratifications to enter formally into force. However, the concept of a 200-mile exclusive economic zone (EEZ), within which the coastal states have effective jurisdiction over fisheries and other living resources, is now generally accepted. Most coastal states, including Canada, have implemented 200-mile zones of one kind or another.

The general acceptance of the 200-mile limit has changed the nature of international fisheries regulation. To accommodate the changes, a new body, the Northwest Atlantic Fisheries Organization (NAFO), was established to replace ICNAF. In NAFO the two functions of scientific analysis and the recommendation of management measures are separate. Management applies only to stocks that are exploited wholly or partly outside the limits of national jurisdiction. For instance, the cod stocks on Flemish Cap, a bank some 500 kilometres east of Newfoundland, are subject to NAFO management recommendations.

The scientific council of NAFO may discuss any scientific matters concerning the living resources of the northwest Atlantic. At the request of the country or countries concerned, it can give advice on the status of stocks and the management requirements for resources within national jurisdiction. This advice has been frequently requested by Canada and by Green-

land, represented by the European Community (EC) or by Denmark, with respect to stocks of animals that move between the two areas, including harp and hooded seals. This advice is not binding and coastal states may follow or ignore it. As the recommendations by ICNAF were binding on members, subject to an objection procedure, ICNAF differed fundamentally from NAFO in this respect.

The present NAFO arrangement has much to commend it. Since substantial numbers of the harp and hooded seals breeding in Canadian waters are caught off west Greenland, it is important to have some formal arrangement for regularly bringing together statistical and other information from the two countries. In the NAFO scientific council, issues are discussed both by specialists studying the resource under review and by a wider group of scientists. This exposure to a range of ideas and experience often improves the quality of the scientific analysis. A similar arrangement exists within the International Council for the Exploration of the Sea (ICES), of which Canada is also a member. ICES is concerned mainly with the northeast Atlantic.

A negative aspect of both NAFO and ICES is that they are closed bodies. The scientists, most of them from government fisheries laboratories and similar institutions, attend the meetings as members of national delegations. The reports of these meetings, containing scientific findings and management advice, are usually not available to the public, at least for some time. Thus action may be taken on the basis of advice that was not subjected to public scrutiny and challenge. If, after the scientific advice becomes public knowledge, it is challenged by competent scientists who were excluded from the discussions, those who defend the management action are in a difficult position. The controversy that arose after publication of the report of the ICES ad hoc working group on assessment of harp and hooded seals (ICES, 1983) is an example of this problem.

One way for Canada to increase the credibility of NAFO's statements concerning seals would be to include in its delegation more scientists from the academic community and various non-government institutions. Widening the participation in the NAFO groups concerned with seal-population assessment would make the scientific basis of seal-management advice less vulnerable to criticism.

Convention on International Trade in Endangered Species

The Convention on International Trade in Endangered Species (CITES) was signed in Washington in 1973 and implemented by Canada in 1975. More than 80 countries now adhere to it. As the title implies, the Convention's aim is to aid the conservation and preservation of endangered species by controlling international trade. Most of the species of concern to CITES are listed in one or the other of two appendices to the Convention.

Appendix I includes all species threatened with extinction which are or may be affected by trade. Trade in these species is subject to strict controls including both export and import permits. One condition for an import permit is that "a Management Authority of the state of import is satisfied that the specimen is not to be used for primarily commercial purposes." Monk seals and the Guadalupe fur seal are listed in Appendix I. No Canadian seal is listed in Appendix I.

There are two circumstances in which a species may be included in Appendix II. First, it may be similar in appearance to an endangered species listed in Appendix I, so that effective control of trade in the endangered species can be achieved only if trade in the non-endangered "look-alike" species is also controlled (Article II.2(b) of the Convention: the look-alike provision). A second rationale for listing in Appendix II is that a species, although not necessarily immediately threatened with extinction, may become so threatened if trade is not strictly regulated (Article II.2(a)). The only Canadian seal listed in Appendix II is the northern elephant seal, which is an infrequent visitor to Canadian waters. (See Table 6.1, Chapter 6.)

An export permit is required for trade in species listed in Appendix II. Import, however, requires only the presentation of an export permit (or re-export certificate) and there are no restrictions on commercial use. An export certificate will be granted only if the export will not be detrimental to the survival of the species.

CITES holds its conference every two years. At the 1981 conference, proposals to include harbour and grey seals in Appendix II were unsuccessful. In 1983, the Federal Republic of Germany proposed that all earless seals not already listed be included in Appendix II. This listing would have included all the Canadian species except the fur seal and sea lions in the Pacific. The proposal was held to be justified on two grounds: hooded seals required protection in their own right under Article II.2(a); and the other species should be included under the look-alike provision. The proposal did

not make clear whether the alleged similarity of the other species was to the monk seal listed in Appendix I or to the hooded seal or to both species.

The 1983 proposal was defeated, as was a similar proposal to list hooded seals in Appendix II, that was put forward at the 1985 CITES meeting in Buenos Aires. On the basis of the scientific evidence presented, the decision was probably correct. Considerable doubts exist about the precise status of the hooded seal. Its abundance in the western Atlantic could be decreasing but no evidence was presented to suggest that the decrease was likely to threaten the existence of the species or that strict controls on international trade were needed. The explanation presented to justify the 1983 proposal stated, in part:

> *The proposal ... is primarily to provide control over a number of species involved, or potentially involved, in international trade and not currently subject to national and international regulations (Federal Republic of Germany, 1983).*

As the harp and hooded seal hunt is subject to Canadian and NAFO regulation, these species would not seem to require the controls sought in the proposal. Although CITES concerns are limited to conservation issues, the CITES proposals were motivated more by political concerns held by the seal-protection movement than by scientific concerns about the status of the stocks. In this situation, the strong Canadian opposition to the CITES proposals was understandable and possibly justified. At the same time, a listing in Appendix II could be seen as a useful complement to the quota regulations, while Canadian opposition to the listing was open to representation as opposition to rigorous conservation of the seal stocks.

Conclusions

1. Seals and sealing industries exist in many areas outside Canada, and the experiences of these areas are often relevant to Canadian situations. Sustained harvesting over a long period is possible, provided that adequate controls are applied. In the first instance (as, for example, in Uruguay), these controls need not be based on sophisticated scientific analysis.

2. Seal stocks can, in due course, recover from very low population levels. In some cases, perhaps aided by favourable conditions, the recovery can be spectacular, as it was, for instance, in South Georgia. If numbers have been reduced to very low levels, say, fewer than 100, there can be a loss of genetic diversity, which could have serious consequences for the long-term success of the population.

3. Where seals and substantial fisheries exist in the same area, there is normally some perception of interaction. The extent of such interactions, especially those that involve competition for fish, is usually difficult to determine exactly, as in Scotland and South Africa, for example. Despite this uncertainty and, particularly in western countries, the special interest of the public in seals, effective fishery management requires that seal stocks be included along with the fish stocks of marine ecosystems in the process of optimizing social benefits. Part of the benefit from seal herds (as of that from salmon runs) may be realized in non-consumptive form. Experience in South Africa and Uruguay has shown that "seal-watching" can be compatible with commercial harvesting.

Recommendations

1. Canada should continue to collaborate with all interested countries in the promotion of research into fur seals and in the co-ordination of management measures. Canada should also take an active part in efforts to establish a new international body with responsibility for all elements of the north Pacific marine ecosystem.

2. Canada should seek to broaden the participation of scientists working outside government institutions in those working groups of the Northwest Atlantic Fisheries Organization concerned with seals.

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Chapter 29

Population Control

... there is no single case in the world where scientific evidence, dispassionately evaluated, supports the view that commercial catches will increase if seals are "controlled" by "culling" (Holt, 1985).

We simply cannot continue to absorb the direct costs and enormous losses associated with these surplus seal populations. It is clear that seal populations must be controlled to maintain a balanced marine ecosystem and the peoples and communities [that] depend upon it (Fisheries Association of Newfoundland and Labrador Ltd., 1985).

Introduction

In their submissions to the Royal Commission, a number of organizations and individuals expressed the view that it was desirable to limit the numbers of seals with the aim of benefiting the fishing industry, or increasing the availability of fish or other marine products for human use. Others questioned either the reality of these benefits or the ethical justification for killing seals for this purpose.

The principal reasons adduced for such actions were to minimize:

- reduction of commercial fish stocks by seal predation;
- damage to fishing gear and loss of fish in or on the gear by seal action;
- losses and costs to the industry resulting from the incidence of nematode parasites that depend on seals as a final host.

The seal species about which concern was particularly expressed were:

- grey seal;
- harp seal, in the event of the commercial hunt's ceasing;

- harbour seal, on both coasts;
- Steller and California sea lions.

Most of the considerations which bear on the balance of the arguments for and against continuation or extension of population-control policies have been discussed in detail elsewhere in this Report. The purpose of the present chapter is to bring this information together in summary form as a basis for reaching appropriate conclusions.

In providing for the killing of seals for the purpose of reducing numbers, the government has followed two principal strategies. The first strategy has been organized hunts by government-employed hunters, working to arranged plans. This practice is generally called "culling" in Canada, and it will be so referred to here. It should be noted, however, that this is a rather specialized use of the word, since "culling" as defined in most dictionaries is primarily a selective process and, where killing is involved, is undertaken with the aim of improving the genetic quality of the herd or other population. In the culling of seals, however, the purpose is usually to kill the desired number of animals, and selection, if any, is made only on a basis of age or sex. The second strategy used in procuring the killing of seals for population control has been the offering of a bounty for each seal killed, the bounty being paid on the presentation of a specified identifiable piece of the animal. This practice is generally referred to as "bounty hunting" to distinguish it from commercial hunting or harvesting.

Other management actions which might be taken to reduce the numbers of seals with the aim of benefiting the fishing industry include allowing fishermen to kill seals, either generally or under specified conditions, and providing encouragement and assistance to commercial harvesting. The advantages and disadvantages of these strategies will be discussed later in this chapter.

Submissions Relating to the Question

The Department of Fisheries and Oceans (Canada, DFO, 1985) provided the Royal Commission with valuable information on the culling and bounty programs which have been undertaken in the past. Sea lions and harbour seals on the west coast, and grey seals and harbour seals on the east coast have been subjected in the past to kills of this kind, but since 1976, only grey seals have been hunted. Large numbers of grey seals were culled in 1983 (2,385); the very small (112) and zero kills that took place in 1984 and

1985 respectively were stated by DFO to be intended to avoid interfering with a tagging program. The Royal Commission therefore assumes that DFO's policy does not exclude culling in suitable circumstances.

The Minister of Fisheries for Prince Edward Island (Prince Edward Island, DFL, 1985), and the Departments of Fisheries in New Brunswick (New Brunswick, DOF, 1985) and Nova Scotia (Nova Scotia, DOF, 1985), all expressed concern about the dangers of increasing seal populations and supported programs to reduce their numbers. All these provinces wished for action on grey seals, and Prince Edward Island specifically urged a bounty on harbour seals, also.

The Government of Newfoundland and Labrador (1985) indicated special interest in the relation of harp seals to the fisheries. It advocated a strictly controlled cull of this species if the market demand did not give rise to a commercial kill sufficient to "protect the fishery resources or maintain the overall health of the . . . herd itself."

Some leading fishing-industry organizations also supported action to control seal numbers. The Fisheries Council of Canada (1985) called for a reduction in the number of grey seals, with the particular aim of reducing the parasite problem; it also appeared to be concerned about the possible effects of expansion of the harp seal population if the present hunt were terminated. A similar view was expressed by the Fisheries Association of Newfoundland and Labrador Ltd. (1985).

The Eastern Fishermen's Federation, whose members operate in the Maritime provinces, provided data on damage caused to fishing gear and catches by grey and harbour seals (Farmer and Billard, 1985), and suggested that steps should be taken to control the numbers of these species in view of the alleged recent increases (Billard and Farmer, 1985).

The Prince Rupert Fishermen's Cooperative Association (1985) expressed concern in its submission about competition between fishermen and seals for fish, particularly salmon, about loss of catch and damage to gear when seals attack fish in nets, and about the effects of nematode parasites in increasing processing costs and reducing value. It urged that the number of seals and sea lions should be reduced "in areas where their abundance has become a problem." It opposed bounty hunting as wasteful and supported development of a commercial harvest as an alternative means of seal-population control.

The World Society for the Protection of Animals tabled documents (Scott, 1985) in which, having pressed for the termination of the commercial seal hunt, it proposed that "a scientific cull" be undertaken "should it prove necessary by scientific analysis to remove a number of seals in the interests of environmental protection." It did not define the "interests of environmental protection" or suggest how these might relate, if at all, to what the fishing industry would appear to regard as preventing an overpopulation of seals.

A number of organizations interested in the protection of seals made presentations which implicitly opposed culling or bounty hunting. A specific statement was presented by Greenpeace International, which tabled its formal policies regarding seals (Bøe, 1985). This policy includes opposition to "the culling and bounty hunting of seals done in the name of protecting fish stocks." It specifically applied this policy to harp, grey and harbour seals.

Should Seal Populations Be Controlled?

The opposition to culling was based on two distinct arguments. One is a technical argument, that the estimates of losses caused by seals and of the benefit to be gained by reducing their numbers are not accurate enough to justify killing the animals. The other is the ethical argument that the economic benefits, even if as large as claimed, would not justify the killing. Dr. S.J. Holt (1985), in his brief to the Royal Commission, discussed the first argument. He examined some mathematical aspects of the relationship between the size of the seal populations, the amount of fish they consume, and the resulting amount available to the fishing industry. He stressed the lack of knowledge of the relationship between the various species in the marine biological community and concluded that "engagement in a seal-culling programme without such knowledge means taking an unknown risk with respect to the seal stocks, possibly at considerable expense . . . with little prospect of significant benefit to the fisheries."

Uncertainty

There are good reasons, which have been discussed in Chapters 24, 25 and 26, why it is difficult to obtain accurate estimates of any of the three classes of loss to the fishing industry. Suggestions have been made in those chapters as to how some of these estimates could be improved.

The estimates of the extent of gear damage and of the losses caused by parasites can probably be improved, although they will never be as precise as other economic figures, such as the size or value of the catch.

The uncertainties surrounding the effect of competition between humans and seals will be much less easy to reduce; they arise both from inadequacies of the data (e.g., what species of fish are eaten by a given species of seal in a given area at a given season), and from problems of interpretation (e.g., what would be the effect on fisheries of changes in the consumption by seals of fish of a given species by a given amount). Further research should ultimately help to reduce the bounds of uncertainty, although a very great increase in the amount of data will be required; but because so much of the uncertainty arises from problems of interpretation, it is likely to remain impossible to express the range of likely values of the losses in terms of statistical distributions. The limits quoted in Chapter 24 for the present losses attributable to the various species of seals are based on subjective assessment of the likely level of uncertainty in the various parameters involved and not on any statistical analysis of the data.

Nevertheless, the Royal Commission believes that the estimates of the losses which it has developed are reasonable, that they provide a reliable measure of the general level of losses caused by seals to the fishing industry, and that this measure can be used as a basis for discussion of the desirability or undesirability of controlling seal populations. The possibility does exist that the true values lie outside the ranges quoted, but it seems proper to require those wishing to assert that the values are significantly too high or too low to go beyond a simple assertion of this possibility. They should suggest what assumptions made in deriving the estimates presented here are, in fact, wrong and propose alternative assumptions, if possible with some supporting evidence, and examine the consequences of using these alternative assumptions.

Public Opinion

Public opinion on the acceptability of killing seals for the economic benefit of the fishing industry will depend to a large extent on the magnitude of the benefit perceived, as well as on the numbers of seals it is proposed to kill. In general it can be expected that the greater the benefit, the larger the proportion of the population that would consider justifiable the killing of, say, 10,000 seals. The monetary amounts involved are so large, however, compared to those usually handled by most people that it may be difficult,

without further study, to know what proportion of the public would regard an annual saving of, say, $10,000,000 as adequate justification, compared to the proportion which would regard $200,000,000 as adequate justification.

The question of uncertainty will also affect public opinion. If it were known, for example, that the loss was definitely $100,000,000, public opinion might be different from public opinion if it were known that while the best estimate of the loss was $100,000,000, it might well amount only to $25,000,000.

The extent of the uncertainties must also modify the way that management measures are applied. It will not be sufficient to determine, on the basis of some chosen estimates, what appears to be the best policy and continue to apply it without further review. It will be necessary to review regularly what is happening to the stocks and to the estimate of damage, and take action accordingly. It must be recognized, as discussed in Chapter 24, that it will be difficult, unless very drastic changes occur in seal populations, to demonstrate directly the impact of measures to control seal populations on the availability of fish to fishermen, and to differentiate them from changes due to the effects of natural fluctuations. This difficulty emphasizes the need to regard all population control operations, including a formal decision not to implement a cull, and thereby to allow the population to expand, as experimental and to ensure that they are accompanied by well-planned research programs to determine their effects, both on seal populations and on fish stocks and catches. This point is considered further in a later section of this chapter.

The point made by Dr. Holt (see above) must be recognized, but a lack of complete knowledge is not the same thing as lack of any knowledge. In dealing with any natural system it will always be possible to argue that knowledge is incomplete, so that failure to take action because full knowledge is lacking could be regarded as irresponsible if the available evidence points clearly in one direction. Thus, the fishing industry might regard failure to take action in relation to some seal populations as irresponsible in the same way that earlier failures to control the taking of seals and other marine resources are rightly regarded by conservation groups as irresponsible.

In Chapter 11 it was shown that there is a strong view among the public that it is wrong to kill seals unless there is a good reason for so doing. This is a matter of demonstrable fact that must be taken into account in setting public policy.

While it is clear that the public demands an adequate justification for killing seals, it is less clear what benefits from killing seals would constitute a justification. In this matter there seems to be some inconsistency in the public attitude towards killing seals and killing other species for sport or for food. Culling of seals for economic benefit to the fishing industry lies in the grey area between hunting by aboriginal peoples for subsistence (which seems to be acceptable to nearly everyone) and killing seals for wholly trivial purposes (which is generally rejected).

In the face of uncertainty, the choice of action to be taken has sometimes been seen as implying a need to decide between giving the benefit of the doubt to the seals or to the sealers and fisheries. This view can overemphasize the degree of conflict between the two sets of interests. What should also be emphasized when uncertainties exist is the need to look at the effects of errors of different kinds on both seals and fishermen, and to recognize that at least for large errors, the effects of making a mistake in one direction may be much more dramatic than those of making errors in the other. For example, if a seal stock is very severely depleted by a large overestimate of the numbers that can be killed, it will take a long time to rebuild, while if too few seals are killed, this error can easily be rectified. Similarly, errors that lead to a large build-up in parasites may take a long time to rectify. In addition to showing the need to avoid errors in the direction in which effects may be harmful and hard to rectify, this points to the need to approach these problems in a step-by-step manner. Actions to change the current situation should not only be subject to careful review before further action is implemented, but in most cases, too, the steps should be no larger than is necessary to have a reasonable chance of achieving identifiable results. The smaller the step, the more difficult will it be, and the longer will it take, to reach any conclusions about the resulting changes.

Effect of Fishing

Another factor which can affect the development of policy on the control of seal populations is the effect of external influences, particularly fishing and environmental changes, on fish stocks. If a stock becomes less abundant because of overfishing or changes in climate, it may be that no reduction in the predation by seals could restore it to its earlier abundance. Such reduction might, however, bring about some increase in abundance which would lead to some additions to catches. Nothing much can be done about climatic changes, but if a stock has been overfished then the important question which arises is whether any reduction of seal populations is justifi-

able until all possible steps have been taken to bring fishing pressure to a proper level.

The fishing industry is well aware of the problems of overfishing and the need to remedy them. The conservation groups have emphasized that seals should not be the scapegoats for failures in fishery management. Differences of opinion will arise when action has been taken to correct overfishing and the industry still believes that it would gain by a reduction in seal numbers.

If the adjustment of the amount of fishing has gone as far as it should, and the fishing mortality has been reduced to an appropriate level, overfishing should no longer be an issue in determining future policy on the control of seal populations.

A more common situation at present is one where some, but not complete, action has been taken; the less controversial methods of reducing fish mortality may have been taken by means such as phasing out foreign fishing, for instance, but the amount of fishing may be still too high according to objective measures of optimum rates of fishing.

Further progress towards the optimum fishing level may be made difficult by such practical problems as finding alternative employment in isolated areas where there are too many fishermen for the local resources to support.

In this situation the fishing industry's reaction would presumably be that if control of fishing activity has gone as far as is immediately practicable, and if measures to limit the consumption of fish by seals would give some benefits, then these measures should be taken. Some environmental groups might believe, however, that as long as benefits can be obtained by more stringent controls on the amount of fishing or by other resource-management measures, these measures should be taken, rather than measures to benefit fishermen by controlling seals (e.g., Bøe, 1985).

This argument is a special case of the general benefit-cost argument concerning the morality or ethics of killing seals, discussed in Chapter 12. It suggests that when looking at a particular situation where the killing of seals might be considered, the analysts should examine not only the expected benefits from the kill, but also the extent to which somewhat similar benefits might be obtainable by other methods, including control of the amount of fishing, and the social and economic costs of these methods.

The Royal Commission believes that the diversity and strength of public opinion about the killing of seals is such that no decisions to implement a cull or bounty program should be made without prior public consultation and implementation of a careful program to explain the reasons to the public and to determine public reaction. Any program undertaken without this consultation would risk incurring wide opposition and could lead to the same kind of anti-sealing campaign that occurred over the hunt of whitecoat harp seal pups.

Past and Present Practices

Only a few seal species have been the subject of organized attempts to reduce their numbers in Canada. These are described below.

East coast

Grey Seal

Culling was undertaken in 1967–1983, but only in a limited area in and near the southern part of the Gulf of St. Lawrence. Something over 17,000 animals were killed in this period, an average of 1,000 per year. Killing was done on the breeding grounds, and 80% of the seals killed were pups.

A bounty was initiated in 1976; the Department of Fisheries and Oceans stated that this was largely as "a measure to allow fishermen to destroy seals which were damaging their nets and traps" (Canada, DFO, 1985). The number of bounties claimed in 1976–1983 was 5,751, an average of about 720 per year, but the number of seals killed by bounty hunters may have been as high as twice this number (Canada, DFO, 1985, p. 81).

Harbour Seal

There has been no cull of harbour seals on the east coast. There was a bounty on harbour seals until 1976. Since that time special permits have been issued in certain localities to allow fishermen to destroy "nuisance harbour seals." Between 1950 and 1971, the number of harbour seals for which bounties were claimed was about 16,000, of which approximately 27%

were pups; the annual kill declined from about 1,000–1,400 in the early years to about 400 at the end of the period (Boulva and McLaren, 1979). No data are available on the number of harbour seals killed under the bounty scheme after 1971, or under special permits (Canada, DFO, 1985).

West Coast

Steller Sea Lion

This species has been subject to a series of culling campaigns over several periods of years beginning in 1912; these campaigns are discussed in some detail in Chapter 22. The last such campaign was carried out in 1958–1966, when about 11,000 sea lions were killed, an average of 1,200 per year. There has never been a bounty scheme for this species, and since 1970 it has been protected under the federal *Fisheries Act* (Canada, DFO, 1985, p. 89). About three-quarters of the animals were killed on the rookeries, and about 15% of the total killed were pups (Bigg, 1985a).

California Sea Lion

This species was scarce on the Canadian coast until the time when protection was extended to it under the federal *Fisheries Act*; it has therefore not been the subject of any significant control program.

Harbour Seal

Harbour seals were killed for the purpose of reducing numbers during 1914–1969, mainly under a bounty scheme (up to 1964), but also by organized hunting and by fishermen. The average number of bounties claimed over 1914–1964 was about 2,900 (Canada, DFO, 1985; Bigg, 1969). No data have been available on the numbers killed in organized hunts or by fishermen. The total number killed by bounty hunters would be substantially more than the number of bounties claimed, perhaps twice as many.

Effects of Past Control Operations on Seal Populations

The available information on the sizes of the seal populations, the changes over the years, and the current trends have been discussed in some

detail in Chapters 21 and 22. The present section is concerned with that part of this information which bears on the effects, if any, produced by the former control programs.

East Coast

Grey Seal

The grey seal population has been increasing in recent years. The data bearing on this have been discussed in Chapter 21, and have led to the conclusion that the population as a whole is almost certainly increasing. On one major breeding ground, Sable Island, where no culling has been undertaken, the population is increasing by perhaps as much as 13% per year. There are, however, no reliable data to show whether, and at what rate, the population is increasing in the parts of the southern Gulf where culling has been going on. Thus, although the overall population is almost certainly increasing in spite of the culling, it is by no means clear whether this increase is primarily a result of the expansion of the Sable Island population.

Harbour Seal

As stated in the review of the status of harbour seals (Chapter 21), the bounty program in effect between 1927 and 1976 produced a decline in the population; between 1950 and 1970 this decline occurred at a rate of about 4% per year. Since the bounty was terminated in 1976, the population has been slowly increasing, probably at about 1%–2% per year. Despite this apparently slow rate of increase, the Royal Commission was informed (Canada, DFO, 1985; Prince Edward Island, DFL, 1985) that fishermen were concerned about increasing damage from these seals. It may be that this concern is partly the result of seals becoming less timid in approaching fishermen's gear in the absence of hunting.

West Coast

Steller Sea Lion

The control program in place in 1913–1969 led to a reduction in the breeding population of the Steller sea lion on the British Columbia coast from about 11,000–14,000 to about 4,800–6,600. The population did not re-

build after hunting ceased in 1969, but establishment of a large rookery just across the Alaska border has probably enabled the number of Steller sea lions feeding in B.C. waters to return to a level similar to, or not much smaller than, that in 1913. If this is so, any further major increase in this population seems unlikely.

Harbour Seal

During the period prior to 1970, when the harbour seal population was subject to bounty or other hunting, it seems to have been fairly stable in size. Since the cessation of hunting it has been increasing steadily, possibly by as much as 10% per year. There is no direct evidence to suggest that the rate of increase is yet slowing down, although it obviously cannot continue indefinitely.

Practical Aspects of Population Control

Costs

The costs of culling operations will depend on the strategy to be employed. They will be least, per seal killed, when several hunters can travel together and kill seals which are concentrated in large numbers on a limited area of land, such as breeding colonies on islands. Most of the major operations which have been undertaken by the Department of Fisheries and Oceans, such as those against Steller sea lion rookeries in British Columbia, and against grey seals in the Maritimes, would fall into this category. Strategies which reduced the number of seals a hunter could kill in a day and increased the distance he had to travel between kills would be more expensive, possibly by a large amount. Operations spread over a wide area and aimed at killing seals on their feeding grounds would fall into this category; they might be considered in order to provide representative samples for scientific purposes. They might also be more acceptable to public opinion.

The Task Force on Seal Borne Parasites (Canada, DFO, 1983) proposed a series of options for the culling of grey seals. The suggested numbers ranged from 17,000 (believed to be the maximum possible) down to 8,600, with 50%–60% comprised of pups. This is roughly five to 10 times the recent average level of kill. These operations were apparently to be carried out in

the same manner (by concentrated killing in the breeding areas) as past DFO operations, and the estimated costs ranged from $30,000 to $72,500. The Committee on Seals and Sealing (COSS) pointed out, however, that these figures did not include the salaries of the hunters and other overheads, and suggested that a further $50,000–$100,000 would be required (Ronald, 1983a). If these figures are accepted as having at least indicative value, the cost of such a major grey seal cull would be about $80,000–$170,000, which appears to be of the order of $10 per seal killed.

Culling operations, up to the present, have generally been directed at concentrations of seals on breeding grounds, for example, where it is possible for a few men to kill a large number of seals in a relatively short time. This is a strategy that will tend to minimize the cost per seal killed. If it were considered desirable to undertake more diffuse operations in order, say, to obtain a more representative sample of the population for use in scientific studies, the number of seals killed per man per day could be substantially lower, and costs per seal killed could rise accordingly.

The basic cost of a bounty program is the cost of the bounties themselves, but to this should be added the costs of publicity programs, supervision, handling of payments, and so forth. Since 1979, the bounty paid on grey seals has been $50 for an adult and $25 for a juvenile. The average basic cost appears to be in the vicinity of $20,000–$30,000 for the 720 animals killed. At this level of bounty, the cost per seal killed appears to be more than twice that for an organized cull. This should not be surprising. Culls are generally carried out at the least possible cost. Bounty rewards must be set high enough to cover costs of the operation and leave enough profit to attract fishermen and others to go "bounty hunting."

The Task Force on Seal Borne Parasites (Canada, DFO, 1983) also pointed out however, that the numbers of seals killed under the bounty scheme had been diminishing; it therefore proposed that the bounty should be increased to $100 per adult seal and $50 per juvenile. This increase would make bounty hunting considerably more expensive per seal killed than culling, perhaps by four to six times. Any additional rewards for research material, like the rewards of $50 and $12 respectively now paid for brands and tags on harbour seals, would add to the costs.

Allowing fishermen to kill "nuisance seals" is, of course, a much cheaper option.

Humaneness

The great majority of the animals killed in past control programs have been shot, although some pups were clubbed. The question of the humaneness of these operations is discussed in some detail in Chapter 20.

The clubbing of grey seal pups can apparently be acceptably humane provided that it is done in a proper manner. In organized hunts under the control of DFO officers, it should be possible to achieve this standard, although the Royal Commission has not received any reports by independent observers on the standards of recent practices. The Commission has not, in fact, been informed of the respective proportions of grey seal pups that are clubbed and shot. It has, however, been told that although in the past Steller sea lion pups have been killed by clubbing, this method of killing is not easy to use effectively because of the thickness of both the skull and the hide (Bigg, 1985b). Any killing of these pups should therefore be done by shooting.

The humaneness of shooting operations depends primarily on obtaining the maximum proportion of quick kills, that is, animals are either killed instantly or, if wounded, despatched rapidly thereafter. There appear to be considerable differences among past control operations in this respect.

The accuracy, and therefore the humaneness, of shooting depends greatly on whether the shooter is on a stable base, and whether the seals are on land or in the water. Moreover, when seals are shot in the water, wounded animals may submerge and either escape or die slowly.

Whatever the kind of seal and the hunting technique, much depends on the care and skill of the hunter, and for this reason organized hunting under DFO control should be preferred to bounty hunting by individual hunters, whether or not they are professional fishermen. In addition, most seals shot for bounties are probably fired at while in the water. The Committee on Seals and Sealing has described bounty hunting as "inefficient, ineffective, and often inhumane" (Ronald, 1983a).

There has been some criticism of the wounding rate in the grey seal cull (Webb, 1984), although this criticism might possibly be overcome by the use of more powerful ammunition or by restricting the killing to pups. The Royal Commission was advised, however, that shooting of adult Steller sea lions is unsatisfactory, both because of the size and tough hides of the animals, and because local conditions require that most shooting be done from boats, which makes accuracy uncertain (Bigg, 1985b).

It was also suggested to the Royal Commission (Bigg, 1985b) that under suitable conditions, harbour seals can be effectively and humanely shot in the water by careful marksmen on land.

It appears, therefore, that acceptable standards of humaneness could, with adequate supervision, generally be achieved in population-control operations involving the kill of grey seal pups (either by shooting or clubbing), Steller sea lion pups (by shooting), and harbour seals (by shooting). In all cases, however, the operations should be undertaken by trained and responsible people and be under DFO supervision.

The Royal Commission realizes that although the killing of pups in culling operations is more likely to be humane than is the killing of adults, it is also more likely to cause an adverse public reaction. This would be particularly true if the pups were to be killed by clubbing.

Control Operations as a Source of Data

Any management program, to be effective, must be based on knowledge of what is being done. It is therefore important to know what numbers of seals are killed in any control operations and, preferably, the numbers of pups and adults, and the numbers of males and females. The information obtained from supervised hunting is generally better than that from bounty hunting, and better still than that from permit operations. There will always be an unknown loss rate, but DFO considers it will be lower in culling of grey seals than in bounty hunting, both because culling is a directed activity and because only high-powered rifles are used (Canada, DFO, 1985, p. 83). The Royal Commission believes that this view is correct; it also seems probable, in the Commission's view, that a more reliable estimate of the rate of loss can be obtained in culling operations carried out under direction, than in bounty or permit hunting. The Task Force on Seal Borne Parasites (Canada, DFO, 1983) stated that fishermen estimated the loss rate in bounty hunting of grey seals at 25%; Mansfield and Beck (1977) estimated loss rates at 76% in spring and early summer, and 50% in late summer and fall. For harbour seals Bigg (1969) estimated the loss rate at 50%.

The Department of Fisheries and Oceans in its brief states that the bounty program was of value in providing a random sample of the seal population, which can be used to determine its age structure; this information is vital to population assessment (Canada, DFO, 1985). This may be so because the portion of the animal required for payment of the bounty is the jaw, which contains teeth from which the age of the animal can be determined.

No studies seem to have been undertaken to determine whether or not there are, in fact, any biases in the sample of population obtained by bounties. The present culling procedure for grey seals, taking mainly pups and some breeding females, does not provide a random sample of the population. It would seem possible, however, to devote part of the supervised effort to the taking of random samples of the population by trained hunters, as Fisher (1952) advocated for harbour seals on the west coast. This practice would greatly increase the value of the information obtained for scientific purposes such as monitoring the status of the stock. Cull programs, if suitably designed, could also provide very useful information on feeding and on the incidence of parasites.

Methods of Control

Up to the present, seal control has been carried out in Canada only by killing a certain number of animals. The killing techniques have consisted almost entirely of shooting and clubbing. The merits and demerits of these methods have been discussed briefly earlier in this chapter and more fully in Chapter 20. In theory, at least, other killing methods are possible, and it might also be possible to reduce seal numbers, at least at critical times and places, by methods other than killing.

Other Methods of Killing

Although several alternatives to the existing methods of killing seals are theoretically possible, none appears at present to be acceptable. Both netting and poisoning could be effective, but for reasons discussed in Chapter 20, they would both be unacceptable on the grounds of humaneness.

Fisher (1952) describes what was apparently a successful attempt to kill a substantial number of harbour seals by using dynamite to blow up the sandbar on which they were resting. He suggests that this technique could be effective elsewhere where it is impossible to approach closely enough to kill the seals in other ways. As described the method is probably quite humane, since the seals were "blown to pieces." The Commissioners doubt, however, whether such a procedure would gain public acceptance at the present time.

Biological control of undesirable mammalian populations has been applied with considerable success in some cases, such as that of rabbits and myxomatosis in Australia and the United Kindgom. Apart from the techni-

cal problems of finding an appropriate pathogen if, indeed, one exists, an attempt to apply this method to seals would be open both to strong humanitarian objections and to the objection that even if some animals were killed, it would be impossible to regulate the resulting population level; on the one hand, the reduction in population might be uselessly small, or, on the other hand, excessive. The adoption of such a proposal cannot, therefore, be recommended.

Methods of Reducing the Impact without Killing Seals

The Task Force on Seal Borne Parasites (Canada, DFO, 1983) discussed the possibility of checking reproduction of seals by administering anti-fertility drugs to breeding females; this suggestion followed some preliminary biochemical studies carried out by Ronald (1983b). The Task Force considered, however, that "the logistics of administering [the drug] to most adult females are almost impossible." It also pointed out that such a technique, even if successful, would bring about only a gradual decline in the population. It therefore did not recommend further exploration of this approach, and the Royal Commission would concur with this view.

Local reduction in numbers through dispersing seals, as distinct from reducing the size of the whole population, might be beneficial in reducing losses from damage to gear and damage to or loss of fish caught by the gear. The development of scaring devices for this purpose seems to show some promise; it is discussed briefly in Chapter 25. So far as the Royal Commission was informed no such research is being undertaken for seals in Canada at present, and the Commissioners believe that favourable consideration should be given to well-conceived research on these lines.

One possibility of achieving a long-term reduction in numbers of seals while avoiding large-scale killing of animals may be through a continuing program of disturbance of breeding colonies at the critical time of, say, parturition and mating. Such a program would aim at achieving a substantial reduction in the number of pups produced. It seems most likely to offer chances of success for strongly colonial breeders like grey seals and sea lions. Some Steller sea lion rookeries on the coast of British Columbia have disappeared since 1913 (e.g., Virgin and Pearl Rocks; Bigg, 1985a) following large culling operations. It is not clear from the limited records available how much the actual killing contributed to the seals' disappearance, and how much was attributable to disturbance of the survivors. Observations on grey seal colonies in the United Kingdom have suggested the possibility of

developing such a technique (Summers and Harwood, 1978). A program of this kind might provoke substantial public opposition, however, if it led to females abandoning their pups in any numbers, with the subsequent deaths of pups by starvation.

Further possibilities which might merit consideration would be making breeding areas less usable by such means as changing the nature of the surface or fencing off particularly suitable areas.

Organizational Arrangements

Table 29.1 attempts to summarize the main features of the principal ways in which government-approved seal hunting could be carried on to provide population control. The methods of organizing are largely self-explanatory. Killing by government employees or contractors has been divided into two broad operational forms. The first, killing on breeding grounds, as for example, the culling of grey seals on the Atlantic coast and of Steller sea lions on the Pacific coast, enables large numbers of seals to be killed in a short time, but the concentrations attacked are usually not representative of the whole population. The second, large-scale operations by government-employed hunters covering wide areas, have not been used in Canada, but they could, as discussed earlier, be organized to provide truly representative samples. Such a scheme was suggested by the Task Force on Seal Borne Parasites (Canada, DFO, 1983), and Fisher (1952) proposed a rather similar arrangement for the control of harbour seals in B.C. waters.

A distinction is made in Table 29.1 between arrangements which are laid down for fishermen to kill seals under permit, and arrangements under which permits may be given to hunters generally. The reason is that under the first system, a large proportion of the kill will tend, whether officially or not, to be "nuisance" seals, and their removal should produce a greater reduction of loss caused by damage to gear and loss of catch than would killing the same number of seals in a widespread operation. Licensing other hunters might produce a more diversified kill.

Marketing of Products from Control Operations

If any programs are adopted for killing substantial numbers of seals in order to control the size of the population, every effort should be made to salvage the pelts and, if possible, the carcasses and put them to good use. There are a number of reasons why this should be done.

Table 29.1
Main Features of the Principal Methods of Organizing Population-Control Operations

	Achieve Desired Kill[a]	Limit to Kill[b]	Knowledge of Number Killed[c]	Biological Samples[d]	Humaneness[e]	Cost to Government[f]
Government Employees or Contractors: on breeding grounds	Y	Y	Y	YN	A	H
Government Employees or Contractors: representative kill	Y	Y	Y	YR	A	VH
Bounty Hunters	N	Y*	U	YR	B	VH
Fishermen (permit)	N	Y*	P	N	B	L
Other Hunters (permit)	N	Y*	P	N	B	L
General Public (uncontrolled)	N	N	N	N	C	VL
Commercial Hunters (permit)	Y	Y	Y	S	A	M

a. Achieve desired kill: Y = can kill desired number provided they are available and sufficient staff and funds are used.
N = no effective way of bringing number killed to a target level.

b. Limit to kill: Y = can regulate kill close to permitted level.
Y* = can regulate kill by closing when target achieved provided there is an adequate reporting system.
N = no effective way of limiting number killed.

c. Knowledge of number killed: Y = fairly accurate figures on numbers killed should be available.
U = number of bounties claimed is accurately known but this underestimates the kill by an unknown amount.
P = permit holders may be required to provide records of numbers killed but reliability is always uncertain.
N = estimates of kill require special studies.

d. Biological samples: YR = can obtain samples from kill which may be usefully representative of population.
YN = can obtain samples which are only representative of animals killed.
N = cannot easily obtain samples.
S = can obtain samples by employment of sampling staff.

e. Humaneness: A, B, C = in approximate order of decreasing acceptability.

f. Cost to government VH, H, M, L, VL = in approximate order of decreasing cost per seal killed.

- The waste of potentially useful material is ethically undesirable.

- Failure to utilize the remains would provoke adverse public reaction.

- Large numbers of carcasses, if left to rot would be a source of environmental pollution. Burying might also cause environmental disturbance.

- Use of the pelts and carcasses might offset some of the financial costs of the operations, although the labour and transport costs could equal or exceed the value of the pelts or carcasses retrieved (Canada, DFO, 1983).

The Department of Fisheries and Oceans has advised the Royal Commission that it did try, at one time, to arrange for the pelts of grey seal pups killed to be salvaged and marketed. This attempt was unsuccessful, chiefly because the number of pelts available (about 1000) was apparently much too small to make it economically advantageous for the processing company to send a vessel to collect them. This might suggest, at first thought, that salvaging the skins might be worthwhile in a large-scale operation. A number of factors would be involved, however, in this decision. Among these are the following:

- Skins from some localities, such as Sable Island, contain sand which might damage the processing machines.

- Only skins of grey seals pups can be utilized because those of the adults are too badly scarred.

- Ships sent to collect skins could not get close to Sable Island.

- There would be some additional supervision and handling costs to DFO.

Harbour seal pelts from the west coast were marketed successfully for a time in Europe in the 1960s, but the price apparently collapsed. Whether it would be possible to find a market again, if significant population control operations are considered in the future, seems doubtful, but the effort should be made.

Summary

Considerations put forward in the preceding sections lead to the conclusion that if population-control operations are to be undertaken in

the future, the following essential features should be considered:

- Operations should be under close government control and should normally be carried out by government employees. The purposes of this arrangement are to ensure that
  - the maximum possible degree of humaneness is observed;
  - numbers of seals killed and location of operations are in accordance with plans;
  - proper records are kept of all operations and required biological material is collected.
- Costs will generally be lowest if operations are concentrated on breeding colonies, but such operations will not provide representative samples for population assessment and monitoring. It will be important to take the requirement for information into account in developing overall plans.
- If pups are to be killed, it is likely that clubbing would be a humane method by objective standards except for Steller sea lions. Nevertheless it must be recognized that clubbing creates a repulsive visual image and at present arouses very strong public opposition. This might imply that killing of pups should not be included in a culling program, though use of alternative methods of killing pups (e.g., shooting, perhaps with the Hughes pistol; Hughes, 1985) could also be considered.
- Where seals are creating serious local losses (e.g., damage to fish traps and pounds), and these losses cannot reasonably be prevented by driving seals away or use of government hunters, fishermen might be allowed to kill seals under special conditions, namely that
  - numbers killed are strictly limited and proper records are kept;
  - only acceptably humane killing methods are allowed;
  - collection of biological material useful to population monitoring is required; payment should be realistically related to the time involved.
- If possible the seal products obtainable from seal-culling operations should be used in a non-trivial way.

- Consideration should be given to other means of reducing the productivity of breeding colonies.

Economic Justifications for Population Control

Proposals for programs to limit or reduce seal populations are almost invariably based on the desire to control economic losses to the fishing industry caused by one or more of:

- heavy incidence of nematode parasites in fish;

- direct damage by seals to fishing gear and catches;

- reduction in the abundance of commercial fish by seal predation.

Development of population-control policy involves a decision on whether and by how much to reduce the number of seals or possibly to limit the growth of the seal population by natural increase. Such a decision can be approached in two ways: either in absolute terms by aiming to move the population to, or towards, an identified optimum level, or on a directional basis by seeking to change the population by a certain amount from its current level towards one producing smaller losses or by limiting adverse changes that would otherwise occur.

The first approach involves identifying an optimum, or at least a desirable, level for the seal population. The problems in defining such a level are examined in Chapter 27 with particular reference to the management of the harvesting of economically valuable resources.

The conceptual difficulties stem from the fact that the optimum population level depends on the weight given to the various benefits and costs derived from the seal population. It has been shown in Chapter 27 that a useful reference level in identifying the optimum is provided by the maximum sustainable yield (MSY). If any benefits, in addition to the yield, increase in some way with the numbers of seals, they will tend to move the optimum above the MSY level; intrinsic values attached to living seals in the ocean, and reduction of harvesting costs as seals increase are both examples of such benefits. On the other hand, if there are costs which increase with the seal population, they will tend to force the optimum below the MSY level. The sources of loss that are listed above would fall into this category. It appears very doubtful that it is possible to base population-control strategies

on bringing populations to optimum levels, except in very broad general terms, given the difficulty of achieving an appropriate conceptual balance for any particular population, then determining the population size that meets this balance, either in absolute terms or relative to the unexploited level, and finally estimating the actual population size accurately enough to relate it to the theoretical optimum. It was precisely these difficulties that brought about the practical failure of the International Whaling Commission's New Management Procedure. It may not be feasible to adopt more definite guidelines for a desirable population level in absolute terms than to ensure that the population can continue to meet the three explicit objectives of the World Conservation Strategy, as given in Chapter 27. These objectives, however, do not take into account the further, though rather intangible, benefits which a significant part of the public receives from knowing about, or actually seeing, large numbers of seals swimming in the oceans. It may be possible to quantify some part of these benefits in economic terms such as gain to be made from organized "seal watching" (see Chapter 17), but the Royal Commission has not seen any useful information bearing on the evaluation of these "benefits" in total.

The directional approach to the development of population-control policy seems to offer considerably more hope of success, particularly if the principles discussed above are used to define a lower limit below which the population should not be reduced. In this circumstance guidance could be obtained by trying to compare the benefits to be gained by reducing the population (or preventing its increase) with the costs of the operation. As a first step a direct comparison of costs and economically measurable benefits might be attempted, but it should be borne in mind that social and ethical costs might also be involved.

The small amount of data available to us on the cost of culling operations has been reviewed earlier in this chapter. It appears that the costs of past and proposed operations have been in the range of \$10–\$100 per seal killed. Much depends on the volume of the operations, and considerably higher costs could be incurred if hunting were carried out on a more diffuse basis rather than concentrated on breeding grounds.

The social or ethical costs of a culling operation have at least two components. One derives from the reduction in the numbers of seals; this is the inverse of the benefit discussed above. The other category of social and ethical costs covers those associated with the actual killing of the seals. These costs derive primarily from the distress caused to some people by the thought that the animals are being killed; their extent might depend on such factors as the age of the animals and the method by which they are killed.

There might also be direct economic costs arising from steps to keep the public fully informed about the cull and the reasons why it is being undertaken or, where relevant, the reasons why a cull is not being undertaken.

Relation between Seal Numbers and Costs to the Industry

Elsewhere in this Report (Chapters 24, 25 and 26) the Commissioners have examined, as far as the data allow, the extent of losses caused by seals under present conditions. The principal questions are the following:

- What would be the reduction in the losses incurred in replacing and repairing fishing gear if no seal ever became entangled in a gill net or other fishing gear?

- What would be the reduction in the processing costs if no cod or flatfish contained seal-borne parasites?

- What would be the increase in fish catches if no seal ate a commercially valuable species of fish?

In a strict sense these are meaningless questions, since no one is proposing the elimination of all seals, even if such a course were practicable. Nevertheless, they provide a useful way of approaching the more meaningful questions about the changes in the costs or income of fisheries that might occur if there were changes in the seal population.

These are not easy questions to answer, and it will be helpful to address them in two stages: first, to estimate the average impact per seal, obtained for each significant species by dividing the total impact, as estimated in Chapters 24, 25 and 26, by the total number of seals of that species; and secondly, to consider how this average impact might differ from the rate at which the impact on the fishing industry will change if the seal population changes, as a result, for example, of a culling program or a cessation of commercial hunting.

Average Costs per Seal

Table 29.2 develops indicative estimates of the average losses per seal for those species believed to affect the Atlantic fisheries most significantly. The first lines of the table show estimates of the present annual loss per spe-

Table 29.2
Indicative Average Annual Costs per Seal

	Harp Seals	Grey Seals	Harbour Seals
Annual Costs ($ million)			
Parasites %	1%	98%	1%
(% of $30 million)	0.3	29	0.3
Damage %	5%	80%	15%
(% of $2 million)	0.1	1.6	0.3
Competition for Fish	23–75	30–84	1.6–3.7
Total Cost	23–75	61–115	2.2–4.3
Population	2×10^6	70×10^3	13×10^3
Annual Cost/Seal ($)	12–38	900–1600	170–330

cies per source; the estimates relating to parasites and gear damage have been obtained by distributing the total losses for each source according to a possible percentage schedule. The percentages for parasites have been derived from Table 26.5 in Chapter 26, using the estimated numbers of adult female parasites in each species of seal and the most recent seal population estimates. The percentage allocations for damage to gear are hypothetical, but they are consistent with the comments in Chapter 25 on the relative amounts of damage caused by the various species. The estimates of the competition losses deriving from each species of seal have been taken from Table 24.13 in Chapter 24. The total losses caused by each species are obtained by adding the estimates for each source. The totals are then divided by the estimated populations given in Chapter 21, to obtain the annual loss caused per seal.

The figures arrived at can only be regarded as very approximate, but they do give a useful indication of at least the order of magnitude of the average impact per seal on the fishery. It is evident that the effects are substantial for grey and, to a lesser extent, for harbour seals, but much smaller for harp seals.

How Costs Change with Seal Numbers

The ideal basis for further discussion would be a curve for each species relating the numbers or abundance of seals to their impact on fisheries. In practice only two points on the curve can be identified, and even these have a considerable degree of uncertainty. These points represent the present position, and, with reservations, the origin: no seals, no impact. The reservations about the origin arise because, while the effects of gear damage and competition will fall to zero if there are no seals, there may, in the absence of seals, still be some losses in handling fish infected with nematode parasites, which might be transmitted through other kinds of animals. This effect, however, is believed to be small.

The simplest assumption is that of proportionality: that the impact is proportional to the number of seals so that average impact is constant. This assumption is unlikely to be strictly correct, but the probability of, and the extent of departure from, proportionality will be different for different types of impact.

At this point, it will be useful to distinguish between the average cost per seal, the marginal cost, and the average cost per seal of a given change in population level. The first has been discussed above. The marginal cost is the change which would occur in the total losses if the seal population were changed by one seal. It is equivalent to the slope of the curve of cost versus seal population at the given population level, and may therefore change with the population level if the relation is not proportional. It is the appropriate form of cost per seal to use if the strategy under consideration is maintenance of the seal population at the current level. The average cost per seal for a given change is the appropriate form to consider if the proposal under review is to change the population from the present to a new, and probably lower, level. It is represented by the slope of the straight line joining the corresponding two points on the loss versus seal-population curve. If this curve flattens off towards the top, this cost will be lower than the average cost and will, in general, tend to approach it as the target population level is reduced. If the curve is S-shaped, there will be an intermediate population level at which the cost per seal for the change is equal to the current average cost.

The relation between the numbers of seals and the costs to the fishing industry arising from the presence of nematode parasites depends both on the relation between numbers of seals and incidence of worms in the fish, and the relation between incidence of worms and costs to the industry. Both these aspects are examined in Chapter 26, but it is quite impossible at

present to express either relation in other than general terms. In those terms, the incidence of worms will tend to increase with the abundance of seals, and particularly of grey seals, which individually carry many more worms than either harp or harbour seals. This relation seems to hold generally, both between different areas (the incidence of the worm is particularly high, for example, in the southeastern corner of the Gulf close to the breeding area of a large concentration of grey seals) and over time (there has been a very great increase in incidence over the last 35 years on the NE Scotian Shelf, coincidentally with a great increase in grey seals and some increase in harbour seals breeding on Sable Island).

The nature of the relationship between the abundance of parasites and the level of costs associated with the detection and removal of parasites is also discussed in Chapter 26. It is concluded that there is a strong positive correlation, but there is no reliable evidence as to whether or not the rate at which costs increase relative to the increase in parasites tends to slow down at higher levels of seal abundance. There are some theoretical reasons, however, for believing that both the rate of increase of parasites relative to the increase in abundance of seals and the rate of increase in costs relative to the increase in abundance of parasites might tend to slow down at higher levels of abundance. If this is so, the rate of increase in costs for an increase in abundance of seals can be expected to slow down at high levels of seal abundance.

The relationship between numbers of seals and incidence of damage to gear and catches is considered in Chapter 25. Again, there is virtually no quantitative information, and the simple hypothesis of a proportional relation seems the most reasonable. A less than proportional relation might exist in some circumstances. Some Scottish data suggest that only a limited number of seals attack salmon nets, and that this number does not increase with the seal population (see also Northridge, 1983, cited in Northridge, 1986). On the other hand, there is the hypothesis put forward in Chapter 25 that "to the extent that increasing seal abundance could add to their pressure on their food supplies, it might cause the individual seal to be more anxious to take the bait from a lobster pot or fish from other fishing gear, and damage might increase faster than abundance." These observations, however, do not constitute sufficient reason to discard the proportional hypothesis. It seems unlikely, in any case, that the true relation will depart very far from proportionality.

The nature of the relation between the loss in value of the catch caused by competition for fish and the abundance of seals was discussed in Chapter 24, and it was concluded that at least in the initial stages of develop-

ing policy to control seal numbers for the benefit of the fishery, it would be reasonable to assume that a reduction in the seal population would bring about a roughly proportionate reduction in losses.

Long- and Short-Term Strategies

Concern giving rise to proposals for population control may be based either on the view that the population is now too big and causing unacceptable losses, as held by some witnesses regarding grey seals (e.g., Fisheries Association of Newfoundland and Labrador Ltd., 1985), or on the fear that unless action is taken, a population will increase to an undesirable level, as in the case of harp seals, in the view of other witnesses (e.g., Rompkey, 1985). Whatever the objective, strategy has to be based on the fact that a program of culling or other hunting does not differ in its effect on the population from a harvesting program. If the kill is greater than the sustainable yield, the population will be reduced, but a continuing kill equal to the sustainable yield will keep the population constant at a level below the unexploited level. Thus, if the population is considered to be above the desirable level, it may be reduced by a single large kill or by a continuing kill for a number of years at a level greater than the sustainable yield. If the former course is to be followed, as was suggested by the Task Force on Seal Borne Parasites (Canada, DFO, 1983) in proposing culls of 8,600–17,000 grey seals, it is necessary, in order to hold the population at its reduced level, to follow up with periodic heavy kills (which was done, in effect, although probably not by prior planning, for Steller sea lions), or with a continuing kill at about the sustainable yield level for the future. The alternative strategy of gradual reduction of the population by a continuing kill somewhat above the sustainable yield level has the advantages of minimum cost at any one time and of providing opportunities for monitoring progress. Its main disadvantage is an increased delay before the results of the program become apparent. A considerable range of data exists which suggests that for many seals the sustainable yield of an already reduced population is in the vicinity of 10% (say 8%–13%) of the population, although it seems to be lower for east coast harbour seals under present conditions. The precise figure will depend on the kind of seal, the actual population level, the age structure of the kill and other factors.

Comparing Costs and Benefits

Comparison of the monetary benefits obtainable by reducing the seal population to, or holding it at, a particular level with the monetary costs of

killing the numbers of seals required to achieve this level has three components. The first is the relation between the numbers of seals killed annually and any change in the number of seals present. The others are the relation between the changes of numbers of seals and the changes in resulting financial losses to the industry, and the relation between costs of killing and numbers of seals killed. Of the last two factors, the first is complex and very little understood at present; in this Report the average impact per seal will be used as an index of the likely value of the cost per seal of any change, though this value may well be smaller if the proposal accepted is to hold the population constant or to change it only slightly. The second is likely to depend very much on the hunting strategy. For a given strategy the costs will probably be roughly proportional to the number of seals killed, unless it is desired, for example, to kill a large proportion of the annual pup production. Costs per seal killed will probably tend to increase also if a substantial reduction in the size of the population takes place.

The relation between the differences in population level and the numbers of seals killed can be examined by standard population-dynamics methods. In the simplest case static situations in which populations are assumed constant at different levels can be compared. These can be portrayed by means of a sustainable yield curve of the usual type (Figure 29.1a). The number of animals which must be killed annually to maintain the population at a given level is equal to the sustainable yield at that level. In the figure the required kills for stability at population levels P_1, P_2, and P_3 will be proportional to the lengths of Y_1P_1, Y_2P_2, and Y_3P_3 respectively. The additional benefits to be obtained annually by keeping the population stable at levels P_1, P_2, and P_3, rather than having no kill, would be proportional to the length of KP_1, KP_2 and KP_3 respectively. Thus the additional benefit per seal killed, as compared to no kill, is given by:

$$B = KP/YP \qquad (1)$$

It is obvious that B will increase as the stable population (P) is reduced, whatever the shape of the yield curve. In Figure 29.1b, B is plotted for the yield curve shown in Figure 29.1a with the net recruitment rate at very small population levels ($r_0 - M$ in the common notation) set at 0.1.

In practice, any decision making based on comparisons of the monetary losses caused by seals and the costs of population-control measures would require information, not about alternative stable states, but about alternative courses of action. Such alternatives might, for example, be between holding a seal population at its current level or allowing it to increase naturally, or between holding a population at its current level or reducing it

Figure 29.1
Idealized Population Yield and Benefit-to-Kill Ratio

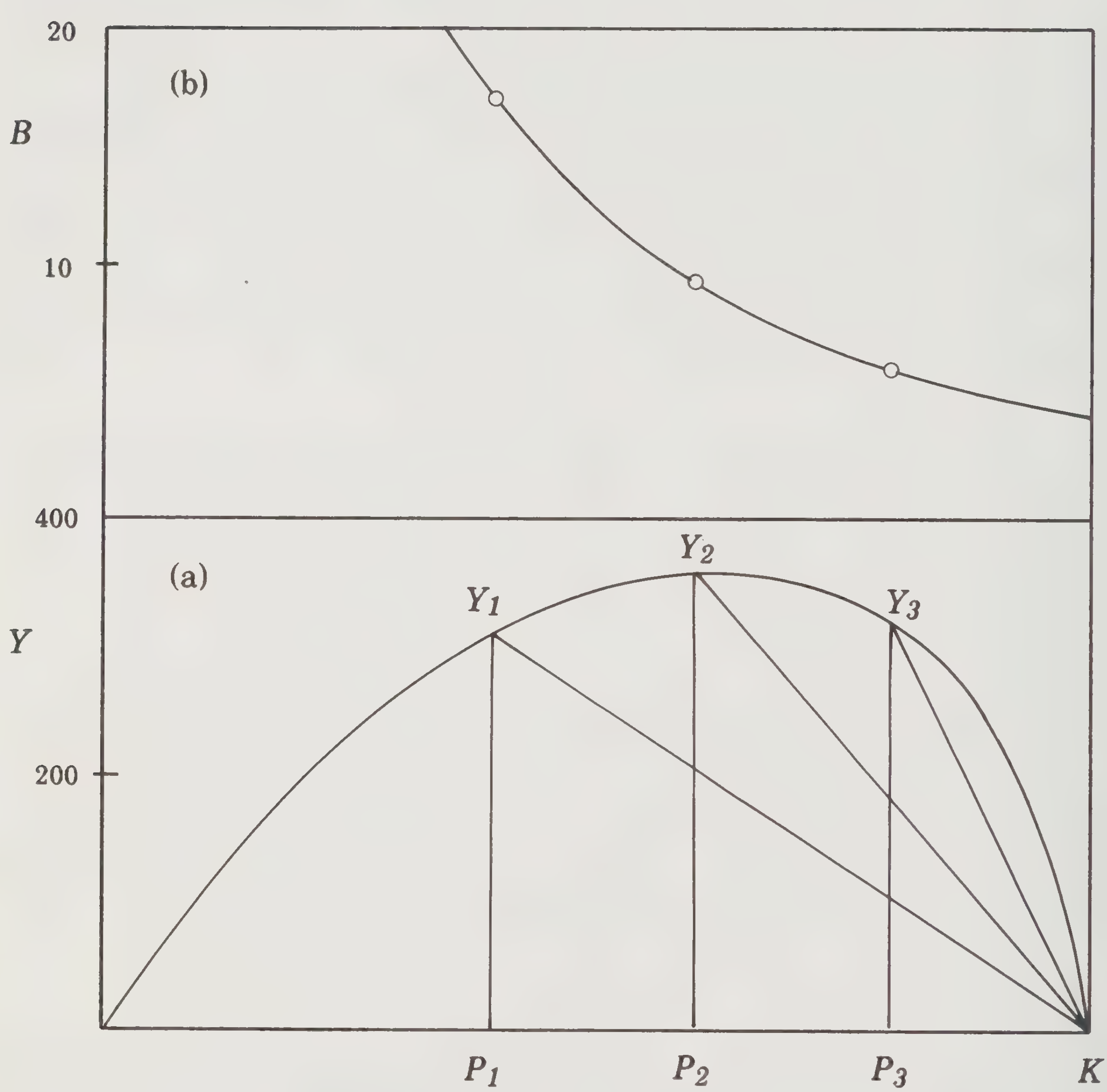

Figure (a). shows sustainable yields (Y_1, Y_2, Y_3) obtainable at population levels P_1, P_2, P_3. K is the unexploited level.

Figure (b). shows for the same curve how B (the ratio of annual saving in loss because the population is at P rather than K, to the annual kill required to keep the population at P) varies with P.

to, and then holding it at, a lower level. Such comparisons should take into account not only current losses and costs, but also future losses and costs as the population changes. It is also reasonable that the contribution of future losses and costs should be discounted as the effects become more remote.

Comparisons of this kind are more complex than the stable situations discussed above, but their theoretical basis can still be examined with a relatively simple model. Such a model is developed here.

Development of a Model

The factors which have to be taken into account are:

(a) The total annual losses increase with the numbers of seals. In the preliminary model, the relation is assumed to be proportional, but extension to allow for other relationships between seal numbers and annual loss is discussed later. The unit of loss is the loss caused by one seal in one year.

(b) The unit of cost is the cost of killing one seal.

(c) Seal populations tend to increase towards a maximum. The relation between the rate of increase and the population size can be described by the following function, which has been used extensively in other work on marine mammals, especially whales (Allen, 1980):

$$r = (r_0 - M)[1 - (N/K)^n] + M \quad ,$$

where N = current population size,
K = equilibrium population size,
r = gross recruitment rate,
r_0 = recruitment rate at very small population size,
M = natural mortality rate,
$(r_0 - M)$ = net recruitment rate at very small population size,
n = a constant which determines the MSY level
(e.g., for MSY = 60% of equilibrium population, n = 2.4 and for MSY = 80% of equilibrium population, n = 11.2)

(d) Future losses and future costs of killing seals should both be discounted; it is assumed to be appropriate to use the same discount

rate for both. Consequently the present values of future losses and costs become negligible after a certain time in the future.

(e) If a population is to be kept stable the number of animals to be killed each year must be equal to the natural increase in the population; and that number is given by:

$$H = N(r - M)$$

The basic equations which arise from this model are:

Population in year t + 1 in the absence of any kill:

$$N_{t+1} = N_t\{1 + (r_0 - M)\,[1 - (N/K)^n]\} \qquad (2)$$

Number of animals killed in year t to keep population constant:

$$H_t = N_t(r_0 - M[1 - (N/K)^n] \qquad (3)$$

Discounted total number of seal years in the future:

$$C = \sum_0^{\infty} Nt(1 - d)^t \qquad (4)$$

where d is the discount rate.

Discounted total number of animals killed in the future:

$$D = \sum_0^{\infty} Ht(1 - d)^t \qquad (5)$$

Ratio of discounted seal-years to discounted kills:

$$B = C/D \qquad (6)$$

Note that B used in equation (6) is not exactly the same as the B used in equation (1), although both compare the losses saved by killing a seal with the cost of killing a seal. In equation (1), B is simply the ratio between the average loss per seal and the average cost of killing a seal. In equation (6), B makes the same comparison, but for a specific culling program; it is the ratio of the long-term discounted losses which would be saved by killing one seal annually as part of this program with the long-term discounted costs of

killing one seal a year. Since the effective comparison is the same, the same symbol (B) is used in the two cases.

The equation in paragraph (c), above, which models the relationship between recruitment rate and seal population size, is a generalized version of the so-called "logistic equation", which is widely used in studies of the population dynamics of marine animals. It is not likely that it exactly fits the actual relationship for any particular seal population, and, in any case, this is, and is likely to remain, impossible to test. Nevertheless, it provides a smooth curve for the relation between sustainable yield and population level which can easily be adjusted to give an MSY at any desired level above 37% of the unexploited level; it is generally accepted that MSY levels for marine mammals are most unlikely to be below this value. The equation also has the advantage of being easily used as a basis for calculations in population models. It would be perfectly possible to use other mathematical formulations to model this relationship, but it must be realized that if they provided a domed sustainable yield curve with an MSY level in the upper part of the population-size range, as seems to be necessary to fit the seal situation, they would, for that reason, lead to rather similar final results if used in the model developed here.

Holding the Population Constant

This model is the simplest case to consider. Here we assume that the two strategies to be compared are to have no cull, thus allowing the population to increase indefinitely until it reaches the equilibrium level, or taking enough seals each year to hold the population constant. Under the first strategy, the relevant losses form the difference between the value of C in equation (4) when the population is allowed to increase and the value of C if the population remains steady. The comparable discounted total of kills is given by D in equation (5) when N is kept constant at the initial level.

The following table shows the values of B, the ratios of seal-years to kills, for various values of the key parameters. The values selected are chosen to cover the likely range of the various parameters. Comparison of lines 1, 2, 3 shows B varying between 7.1 and 4.3 for discount rates between 5% and 15%. Lines 2 and 7 show B at 5.5 and 7.0 when the net recruitment rate varies between 0.13 and 0.08. Lines 2 and 8 show variation in B between 5.5 and 5.3 as the MSY level varies between 60% and 80% of equilibrium level.

	Net Recruitment Rate	MSY level (%)	Discount Rate (%)	Pop./ Eqm. Level	Discounted Loss (seal-years)	Discounted Kills	*B*
1.	0.13	60	5	0.5	7.11	1.05	7.1
2.	0.13	60	10	0.5	2.89	0.53	5.5
3.	0.13	60	15	0.5	1.51	0.35	4.3
4.	0.13	60	10	0.7	1.96	0.52	3.7
5.	0.13	60	10	0.9	0.68	0.26	2.6
6.	0.13	60	10	0.3	3.26	0.37	8.9
7.	0.08	60	10	0.5	2.26	0.32	7.0
8.	0.13	80	10	0.5	3.45	0.65	5.3

Lines 5, 4, 2, 6 show B increasing as the population level decreases from 2.6 at population level 0.9 to 8.9 at 0.3. The shape of the relation is similar to that in Figure 29.1b. In brief, it may be concluded from these calculations that *B* will decrease with increasing discount rate, increasing population size relative to the unexploited level, and increasing net natural rate of increase. It is relatively insensitive to the MSY population level as a proportion of the unexploited level. It appears that for a middle range of population levels (say, between 0.3 and 0.9 of unexploited level) the value of *B* is likely to be commonly in the range 3 to 9. Although these figures are based on particular mathematical formulations, other models based on relations of the same general form can be expected to give broadly similar results.

These figures mean that for each seal killed, the losses associated with 3 to 9 seal-years will be saved when a population is being held constant. In Table 29.2 the average annual costs, or losses, per seal for the most important Atlantic species were estimated. By multiplying these figures by 3 or 9, and assuming that the marginal impact at the population level under consideration is equal to the overall average impact, the approximate range of savings made in this way per seal killed can be obtained, with the results shown in the following table.

The maximum identified costs of culling seals in the past have been in the vicinity of $100 per seal, which is of the same order as the following estimates of savings for harp seals. For harbour and, particularly, grey seals, however, the economic losses which would be saved by killing one

	Harp Seal	Grey Seal	Harbour Seal
Annual cost ($)	12–38	900–1,600	170–330
Saving per seal killed ($)			
B = 3 (i.e., high population and growth rate)	36–114	2,700–4,800	510–990
B = 9 (i.e., low population and growth rate)	118–342	8,100–14,400	1,530–3,970

seal are likely to be considerably greater than any possible monetary costs incurred in killing that seal.

The estimates of the cost per seal discussed above are average costs over all the seals in the population. The relation between overall average cost and either the marginal cost or the average cost per seal of moving between two population levels depends on the shape of the curve relating costs to seal numbers; this was discussed in an earlier section. It is possible, but not demonstrated, that the rate of increase in the loss caused by parasites would tend to slow down as the number of seals increased. Nevertheless, it seems reasonable to assume at this stage that the losses due to damage to gear and catches and to competition for fish stocks are proportional to the numbers of seals; the true relations may, however, depart from proportionality to an unknown extent. In these circumstances, and allowing for the apparent predominance of competitive costs, it appears that marginal costs at present population levels can reasonably be believed not to differ greatly from average costs, but probably to be somewhat smaller.

If the curve does flatten off at about the present population level (i.e., if marginal impact is less than average impact), there must be a part of the curve at smaller population levels where the curve is steeper (i.e., marginal impact exceeds average impact). Thus any argument against a cull, based on the fact that the use of average impacts may overstate the benefits of a small cull, could be balanced by the argument that an effective cull would have to be large enough to bring the population down to a level when marginal impacts are greater.

Reducing the Population

If other strategies are to be considered, such as a strategy to reduce the existing seal population to a lower level and then stabilize it at that level, the above analysis must be extended. The simplest strategy, and the only one which will be considered here, would be to reduce the population to the desired level by a single major operation in one year and then to hold it at that level. In this event the losses which would be saved are those associated with the difference, in future years, of the number of seals that there would have been if the population had continued to expand from its original level, and the number at which the population will now be stabilized. These losses can be discounted and estimated by the model discussed above. The costs of killing would be the full cost of reduction in the initial year, plus the discounted costs of future killing needed to keep the population stable. As an example, these losses and costs of killing have been calculated for a model with: $r_0 - M = 0.13$; MSY level = 60%; discount rate = 10% for several ranges of population change; with the following results.

Initial Population	New Population	Discounted Losses (seal-years)	Discounted Kill	B
1.0	0.5	5.00	0.97	5.1
1.0	0.3	7.00	1.03	6.8
0.9	0.5	4.68	0.87	5.4
0.7	0.3	5.96	0.87	6.8

The range of values of B seems to be similar to those values found in examining the population-stabilization strategy.

Effect of Varying the Cost–Population Size Relationship

Although it is not possible to describe with any certainty the shapes of curves relating losses to seal population levels, it will be useful at this point to examine in a little more detail the way in which average costs per seal, marginal costs and costs for a given change vary for different kinds of curves which might represent the loss-seal population relation.

A number of such curves are portrayed in Figure 29.2a; while none of them can be advanced as representing an actual situation, they represent among them some of the general kinds of relations which may exist in practice. In this figure, V is the total annual loss produced by a seal population of size P; the units are such that P equals 1 for a population at the unexploited equilibrium level, and V equals 1 for the losses produced by a seal population of that size. Curve A represents exact proportionality, curves B and C represent situations in which the marginal cost decreases progressively as the seal population increases, and curves D and E are S-shaped curves in which the marginal cost is highest at some intermediate population level.

In Figure 29.2b the average loss per seal (V/P), calculated from the same functions, is plotted against population size. The curves presented in Figure 29.2a lead to a variety of relations between V/P and population size, ranging from the loss per seal decreasing with population size (B,C), through little or no variation (A,D), to loss per seal increasing with population size (E).

Figure 29.3a shows how the relationship between B and population size (P) varies for each of these curves in the situation where the choice is between holding the population at level P or allowing it to increase naturally to the unexploited level (i.e., no cull). B, as explained earlier, is the ratio between the discounted additional losses (in units of losses caused by one seal in one year) which would be incurred if the population were allowed to increase, and the discounted costs (in units of the costs of killing one seal) of killing enough seals to keep the population at level P. In all instances B increases with decreasing P and, except in the case E, where loss per seal increases with population size, the curves are concave upwards.

Figure 29.3b shows the same relation for the case where the alternative strategies are to leave the population at the unexploited level (i.e., no cull) or to reduce it to, and then hold it at, a target level P. The general shapes of the curves and their relationships to each other are similar to those in Figure 29.3a, except that they are much less steep at lower target-population levels.

Current Problems

This section reviews the seal populations for which control measures have been suggested as desirable by some witnesses, and examines the available estimates of the impact of each population on Canadian fisheries and

Figure 29.2
Theoretical Relationships between Losses Due to Seals and Population Levels

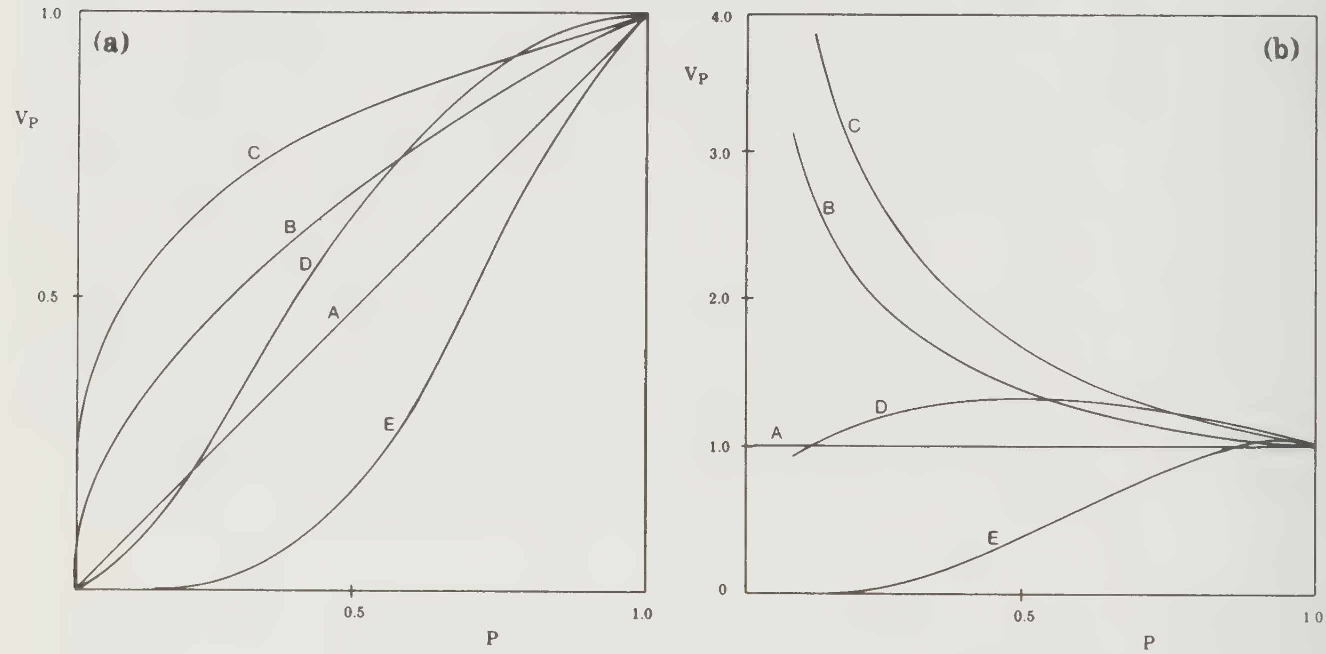

Figure (a). A series of theoretical curves relate the annual loss V_P caused at a relative population level P, to the value of P. P is the ratio of the population to the unexploited level. The relationships of V_P to P are:

A: $V_P = P$
B: $V_P = P^{0.5}$
C: $V_P = P^{0.25}$
D: $V_P = 17.725P^{1.6725} - 16.725P^{1.7725}$
E: $V_P = 45.26P^{4.426} - 44.26P^{4.526}$

Figure (b). For each of the above relations of V_P to P, the loss per seal (V_P/P) is plotted against P.

the types and sizes of control programs which would be required to have specified effects on the population.

Past control operations and proposals for future action in submissions to the Royal Commission have dealt only with harp, harbour and grey seals on the Atlantic coast, and harbour seals and sea lions on the Pacific coast. Bearded and ringed seals have little overlap with commercial fisheries; the northern elephant seal occurs only in negligible numbers. The impact of the hooded seal is particularly difficult to assess; its population is large and probably consumes a substantial quantity of demersal fish, but there is uncertainty as to the amount taken from stocks fished by Canada. The northern fur seal seems to have some impact on the herring and salmon fisheries, but its management has until very recently been under the control of the North Pacific Fur Seal Commission, and its numbers are, in any case, decreasing at present. Further, Canadian waters are visited by only one component of the large Pribilof Islands population, and that for only a limited part of the year.

Harp Seal

The impact of the harp seal on the fisheries has not aroused much interest until recently. A number of witnesses, however, told the Royal Commission of their concern about the possible effects of a fairly rapid increase in harp seal numbers if the commercial hunt is not re-established (e.g., Government of Newfoundland and Labrador, 1985; Fisheries Council of Canada, 1985; Fisheries Association of Newfoundland and Labrador Ltd., 1985). This concern relates to all three aspects of the impact of seals on fisheries which have been discussed in this chapter.

The Royal Commission's estimates of the extent of the present losses are set out earlier in this chapter, but it must be stressed again that these estimates are highly uncertain and should be regarded only as indications of what seems to be the likely extent of these effects. The loss resulting from competition between commercial fishermen and harp seals has a particularly high degree of uncertainty. The main competitive effect is almost certainly related to capelin, but it is not clear how much capelin *in toto* is eaten by harp seals, and how much of this total comes from stocks of actual or potential interest to Canadian fishermen. Moreover, because of the erratic history of the capelin fishery, which in some years was prosecuted mainly by non-Canadian fishermen, it is far from clear what would be the effect on Canadian catches of a given consumption.

Figure 29.3
Loss-Population Level Curves for Alternative Culling Strategies

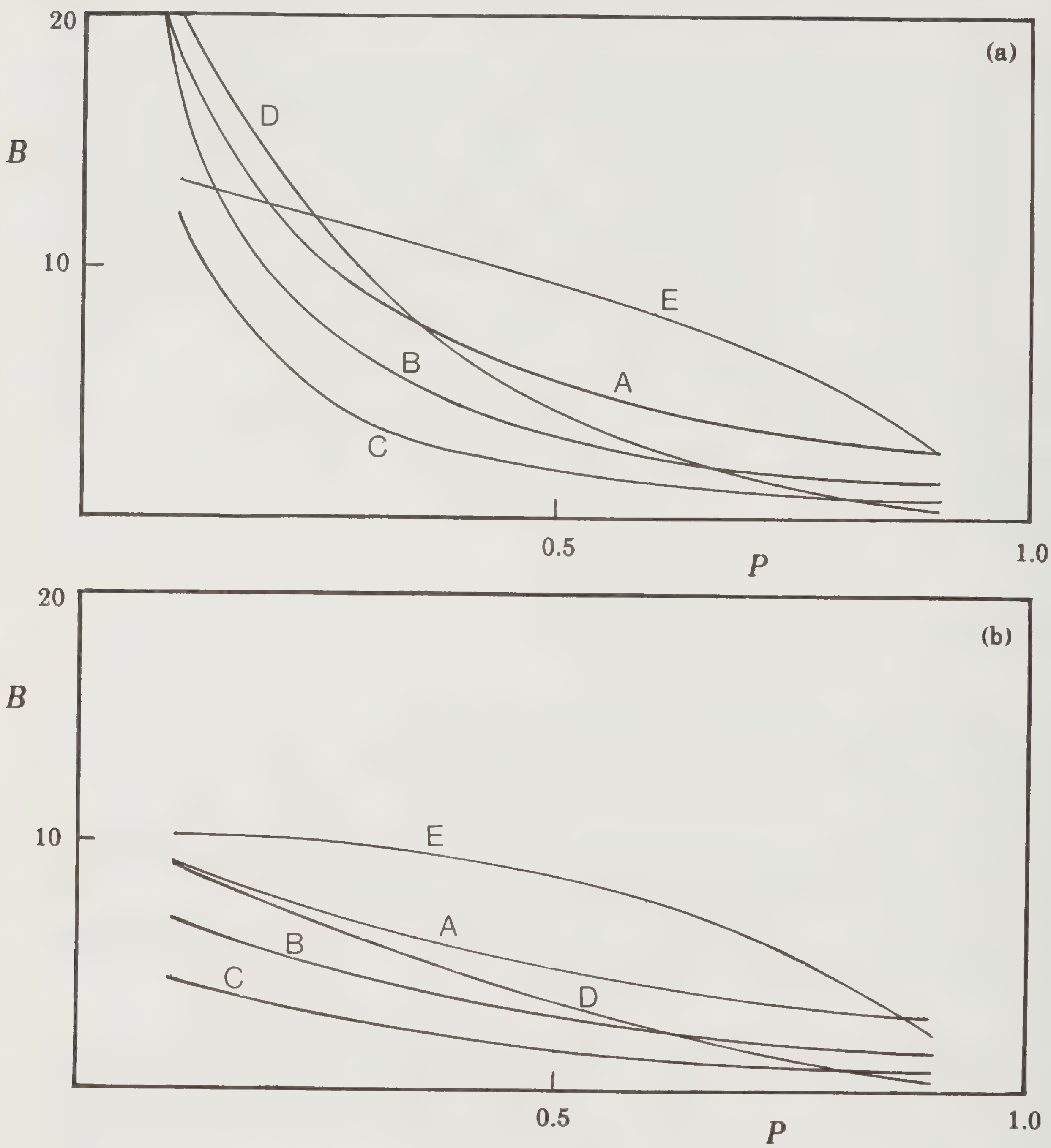

Figure (a). For each of the relations of V_P to P in Figure 29.2a the value of B is plotted in curves (a) against P, where B is the ratio of the additional discounted loss caused by allowing the population to increase naturally from P towards the unexploited level, to the discounted cost of the annual kill required to keep the population at P.

Figure (b). Curves (b) are as above, but with B equal to the ratio of the discounted additional loss if the population is left at the unexploited level, to the discounted cost of reducing it to and holding it at target level P.

If harp seals do increase substantially, some effect would be expected, but whether it would be detectable in the presence of all the other variable factors which affect the catches it is impossible to say. The analysis in Chapter 26 indicates that as far as its effect on the incidence of nematode parasites is concerned, very little knowledge exists at present about the relative potential role of the harp seal to those of the other seals in the southern Gulf. The Royal Commission did not receive any evidence which suggested that harp seals had caused any significant damage to fishing gear and catches until recently. It was told, however (e.g., by Hon. William Rompkey, 1985; Mrs. Alfreda Barker, 1985; and the Wilderness Society of Newfoundland and Labrador, 1985), that in the last two years, presumably as a result of the much greater survival rate of harp seal pups, there had been a noticeable increase in the numbers of young seals becoming entangled in set nets. It is not clear at this stage whether young animals are particularly susceptible to being caught in this way, but if so, this problem may have risen rapidly to a new level with cessation of the hunt, and will only increase further if the breeding stock increases. If animals of all ages are liable to entanglement, the problem will continue to increase, at least for a time, as the more numerous year-classes advance through the population. We have no evidence of the financial losses resulting from damage to nets and loss of catch caused by the entanglement of young harp seals. Table 29.2 gives a rough figure obtained by assigning an arbitrary value of 5% as the share of the total costs of gear damage that is caused by harp seals. It is clear from that table that the true value could differ appreciably from 5% without affecting significantly the total impact, which results mainly from competition.

It is clear from the foregoing consideration that harp seals may present a significant and growing problem to fishermen. The extent of this problem is chiefly the result of the very large numbers of harp seals, and the average damage per seal could be no more than $12. The marginal benefits per seal killed may therefore be of less value than the costs of killing the seal.

At the same time the average damage per seal might be as high as about $40. With due allowance for the uncertainties in extrapolating from average damage to the marginal benefits accruing to the fishing industry of killing one seal, it is therefore possible that there could be a significant benefit from killing a seal which would be additional to any direct benefits accruing from the sale of skins and other seal products. If, for example, the marginal impact is no more than 50% of the average impact, and if the factor B is 5, and the average damage is $40, there will be a net benefit from killing a seal provided that the cost of doing so is less than $100.

The numbers of harp seals that would have to be killed to be effective in controlling the population are high; a kill of about 170,000 (the level of recent quotas) would be needed to maintain the population close to recent levels. A cull of this extent would almost certainly arouse considerable opposition and might be unacceptable to a large proportion of the Canadian public, especially if it included a significant proportion of pups. The large numbers of seals which would have to be killed in a harp seal cull would also make the operation very expensive.

There are too many uncertainties in these calculations for a cull of harp seals to appear justifiable at the present time. However, the calculations do suggest additional economic considerations which should be taken into account if a reactivated harp seal hunt were to be considered in the future. There are reasonable prospects, too, that further research, especially on the composition of the diet of harp seals, will in a few years reduce appreciably some of the wide limits of uncertainty, and provide a basis for better-informed decisions.

Grey Seal

The arguments presented to the Royal Commission in support of population-control measures concentrated particularly strongly on the grey seal. Table 29.2 indicates that the average impact per seal is very considerable, probably in the range \$900–\$1,600 of which at least half is due to competition. Accepting that at current seal population levels, the marginal impact of transmission of parasites is probably less than the average impact, and that the effect of competition might be a little less than the average, the lower bound of the marginal impact on fisheries due to all causes is probably at least \$500. If it is further suggested, to be conservative, that the grey seal population is not far below its carrying capacity, and if it is recognized that the rate of increase seems to be relatively large, but a moderately low discount rate is taken (which seems reasonable in relation to natural resource management), the ratio B may be quite low, say, 3. This would imply that a lower limit to the economic benefit to the fishing industry of the removal of one seal would amount to \$1,500. The upper limit, using the upper value of the range in Table 29.2, and higher values of B and of the ratio of marginal to average impact, could be \$10,000 or more.

This wide range overstates the degree of uncertainty, since it is highly unlikely that all the quantities about which there is uncertainty are at the lower (or higher) end of their probable range. Even so, the lower bound is much greater than the likely cost of culling one seal.

The Royal Commission therefore believes that the economic benefits accruing from a cull would exceed the cost of the culling operation to an extent that is not known exactly but is certainly very substantial; it therefore considers that on purely biological and economic grounds, a cull of grey seals would be fully justified. The question of whether a cull should, in fact, proceed, taking into account public opinion and other factors, is discussed in the final chapter of this Report.

If a cull is implemented, the numbers of seals that should be killed will depend on the objective of the cull in terms of population size: to maintain the present level, to achieve some decrease, or to allow an increase, but a smaller one than could occur naturally. It will also depend on the dynamics of the grey seal population.

In the simplest case, if the target is to keep the population at the present level, the cull must equal the rate at which the population is increasing in the absence of a cull. The Sable Island population is not subject to a direct cull and is known to be increasing at a rate close to 13% per year. The seals breeding elsewhere have been subject to culls, averaging a kill of 2,000 annually over the period 1976–1983, and it is not clear whether they are increasing or decreasing.

The rate of 13% per year may be the natural rate of increase for Canadian grey seals as a whole, but the rate of increase at Sable Island may differ because of a net migration rate into or out of the Sable Island breeding stock, or because some Sable Island seals have been killed on their migration to other areas. In addition, natural factors may be different at Sable Island and in the Gulf. Compared with what is known about growth rates of seal populations elsewhere, 13% seems a somewhat high figure. If it were the true value, to maintain a population of 70,000 at the current level would require an annual cull of about 9,000 seals; a growth rate of 10%, which would be consistent with a number of other seal populations, would imply an annual cull of about 7,000 seals. The above figures are based on a cull spread evenly through the population, but the actual number that would need to be killed would depend on what ages were taken. If, for example, proportionally more pups were taken, the numbers would have to be increased. Again, as a cull takes effect, the age structure of the population will change, and this, in turn, will change the natural rate of increase and the size of the cull even if the total numbers stay the same.

If it is desired to change the population, the desired change must be added to the cull required to keep the numbers constant. If it is desired, for example, to reduce the population to 70% of its current level in five years

(i.e., from 70,000 to 49,000 or by 4,200 annually), the annual kills (using the figures in the previous paragraph), would initially have to be 13,200–11,200 for each year, but could decline somewhat as the population was reduced, perhaps to about 10,500–9,000.

Harbour Seal

On the Atlantic coast losses caused by harbour seals are much smaller than those caused by grey seals. The number of animals is about one-fifth (Chapter 21), the biomass and the food consumption are about one-fifteenth (Chapter 24) and the effective parasite load about one-hundredth (Chapter 26). The average losses per seal seem to be in the vicinity of one-quarter of those caused by grey seals. Compared with harp seals, the total losses caused by harbour seals seem considerably less; however, because of the very much greater number of harp seals the average loss per seal is probably an order of magnitude greater for harbour seals than for harp seals. Although there are complaints of increasing damage by harbour seals (Canada, DFO, 1985), it does not seem likely that the population is increasing by more than a few percent per year. (See Chapter 21.) The need for any attempt to regulate the numbers of this species therefore seems very slight. The analysis in Chapter 21 suggests that a kill of about 150 pups plus 75 older animals would be sufficient to stabilize the population. The only legal killing at present is by fishermen operating under permit to destroy "nuisance" seals. This arrangement is probably adequate to achieve any control that may be desirable in the short to medium term, although it is important that accurate records of numbers killed should be maintained, and that biological material should be procured from as many animals as possible to enable their age and, if practicable, their sex to be determined. It would also be important for the program and its results to be reviewed regularly.

If such a scheme were adopted, it should be applied only to a limited number of fishermen, who would be allowed to kill defined numbers of seals. It would be important to obtain as much information as possible from such a scheme; fishermen should be required to return detailed records of all seals killed and encouraged to return biological material (e.g., jaws, which can be used to age the seals) which will assist in monitoring the population. A reward for such material might be considered.

On the Pacific coast the position of the harbour seal requires more serious consideration. In Chapter 24 it appeared that about 30%–35% of the loss of herring and about 75%–80% of the loss of salmon were caused by harbour seals. Since the harbour seal was protected in 1970, it has been in-

creasing by about 10%–12% per year, and it is impossible to know how long the increase will continue if not checked. (See Chapter 22.) In these circumstances requests from the industry for control of the numbers of harbour seals are likely to require serious consideration.

In the past a recorded bounty kill of about 3,000 animals a year, plus some unrecorded kills, seems to have held the population stable at about one-third to one-half of the present level. If, however, the population is now increasing at about 10% a year and currently numbers about 45,000–60,000, a kill of 5,000–6,000, in addition to any illegal kills which are now taking place, would be required to keep the number of harbour seals approximately steady. If control were considered desirable, a program of killing, say, 7,000–8,000 seals annually would probably cause a gradual reduction in the population; a scaling down of the kill to 3,000–4,000 as the population was reduced could be expected to stabilize the population at a lower level. In any such program it would be essential to ensure that the number of animals killed was accurately recorded, and that adequate biological material was obtained to enable the structure of the population to be properly monitored. A well-supervised bounty scheme might achieve these results.

However, the most serious problems arising from the presence of harbour seals seem to occur at river mouths and other narrow waters where the seals can feed on migrating salmon and take them from gill nets (Canada, DFO, 1985; Fisher, 1952). Since this is so, an alternative and preferable strategy might be one which killed fewer seals but concentrated on locations where seals were actively attacking the salmon run and interfering with fishing operations. Such a program might not only kill some seals which were taking salmon or attacking gear, but also drive other seals away from the critical area to places where they would do less harm. One way in which it could be executed would be to allow fishermen to kill seals within specified times and areas, preferably under a permit scheme, which could provide better records of kills and could also give rewards for biological material which would assist in monitoring any changes in the structure of the population. Alternatively, control could be carried out by crews of trained hunters employed by the government, as proposed by Fisher (1952). Among the advantages put forward by Fisher for such a scheme are:

> *(1) Control methods could be concentrated at will on spots where they are most needed, for example, in the Fraser, Skeena and Nass Rivers, and in gill-netting areas where the seal problem is acute.*

(2) *The system should provide much-needed knowledge on numbers, distribution, food-habits and reproduction, through co-operation with biological studies.*

(3) *The possibility of fraud would be eliminated.*

These advantages seem to carry some weight. Any such program for control by government-employed hunters would have to be undertaken at carefully selected times and places where the destruction would achieve the maximum benefit to the fishing industry. Again, accurate records should be kept of the numbers of seals killed, and as much biological material as possible should be collected from the animals killed. The program should also include regular monitoring to determine its effect on the numbers of seals in the areas concerned.

Steller Sea Lion

Complaints from the fishing industry relating to Steller sea lions mainly concern damage to gear and direct removal of catch from lines and nets; the salmon, halibut and herring fisheries are affected (Canada, DFO, 1985). This species also preys quite heavily on the stocks of salmon and herring. However, the total population on the B.C. coast, including animals from the breeding grounds on Forrester Island in Alaska, is probably about the same as, or possibly somewhat less than, it was in 1956 or at the time of the earliest estimates in 1913. Moreover, the population does not seem to have increased significantly since protection was imposed in 1970. The public impression of an increased abundance in the last few years seems to derive from a combination of an increase in the number of California sea lions visiting southern B.C. waters in the winter and an increase in the number of Steller sea lions migrating into the same area both from Alaska to the north and from Oregon and California to the south, during the same season. The latter move is probably a response to a greater availability of herring in a few recent years.

As noted earlier, the data are not adequate for calculation of either total impact or impact per seal on the Pacific coast. However, examination of the information which is available suggests that much the largest component of the impact of Steller sea lions is likely to arise from their competition for salmon. Any future studies of the problem should therefore pay particular attention to this question.

In these circumstances, the Commissioners do not believe that there is need for any action to reduce the number of Steller sea lions. Current studies aimed at monitoring the numbers of these seals should, however, be continued, and the position should be reconsidered if any significant increase in the overall population is found to be occurring.

California Sea Lion

Only the males of this species have become winter visitors to southern B.C. waters in the last few years. They probably have some impact on the herring fishery in particular, because of the amount they consume and because they get into herring seines and gill nets (Canada, DFO, 1985). Since they probably take a relatively small amount of salmon, the total impact per seal on the fisheries by California sea lions seems likely to be considerably less than that of Steller sea lions. As discussed in Chapter 22, it is not clear why the numbers of this species migrating to southern B.C. waters have recently increased, or whether this trend is likely to continue. Because only a small proportion of the males and no females come so far north, no action in Canadian waters can influence the size of the breeding population. If it were desirable to reduce the numbers in B.C. waters, it would be necessary to kill off each year some proportion of the animals coming up from the south. Unless such an action had some effect in discouraging migration in future years, and this does not seem very likely, the annual kill would have to be continued indefinitely. The number of animals visiting British Columbia has so far been only a few thousand and has actually showed some decrease in 1985. In these circumstances no program for reduction in the number of California sea lions seems to be justifiable, although it will be desirable to continue to monitor the situation closely.

Population Control and Commercial Seal Hunts

The control of seal populations by culls or similar methods is only likely to require serious consideration in the absence of a significant commercial hunt on the seal species concerned. This is because a commercial hunt under appropriate controls could be the most effective method of maintaining a seal stock at a desired level, provided that the kill was large enough to make the hunt economically viable.

The advantages of a commercial hunt over an operation directly implemented by government employees increase as the number of seals to be

taken gets larger. The obvious example is the harp seal. To be effective in maintaining the population either at the present (1986) level, or at some slightly higher level if a moderate increase is held to be more acceptable, the number killed must be close to the present sustainable yield, that is, up to about 150,000–200,000, depending, among other considerations, on the ages of seals killed. A government-operated cull of this size would be extremely costly, almost certainly requiring the expenditure of several million dollars annually.

On the other hand sealers from Newfoundland and elsewhere were taking that number of seals only a few years ago, and most of the men and ships involved still exist and could take comparable numbers in the future. This is probably still true even if no whitecoats were taken, although a limitation to taking older seals would reduce the number of seals which would have to be taken to produce a given effect on the population. The restriction to taking older seals would certainly increase the cost of the operation. The sealers are not now operating on a significant scale, however, because the price they receive for skins is too low.

It may be, therefore, that the most effective way of implementing a cull of harp seals – assuming that it is desired to have a cull of one sort or another – would be through traditional sealing operations on older harp seals, and that the economic viability, and hence the continued existence, of these operations might be achieved by some form of price support for the skins produced. If, for example, there were a guaranteed price for skins of older seals equivalent to that received in 1981, it is likely that many longliners would renew their activities at about the 1981 level. Such a support price would relieve some of the economic and social problems now being felt in many of the main sealing communities. (See Chapter 15.)

The support price needed to reactivate sealing to the level at which it would achieve the desired cull would have to be carefully calculated. It would need to be high enough to generate sufficient interest, but not so high as to give rise to excessive profits or to a level of activity that could constitute a threat to the stock. In any case the number of seals caught should be kept under careful control. Recent history suggests that a gross return of $20–$30 a skin for harp seals would be adequate. With present markets this return might need a support payment that would not be much smaller. The data presented in this chapter suggest that the net benefits to the fishing industry per seal killed are likely to be of this order or rather higher. In other words, the costs of the operation would be less than the benefits, and there would be no net drain on the Canadian economy.

No new principle is involved here. Price support is given to the sealers in Greenland, and support, though not in quite the same form, to Norwegian sealers. In Norway at least, a major consideration in supporting sealing is the losses which would accrue to the fisheries if the seals were to increase in the absence of a hunt. In Australia a commercial hunt is encouraged to achieve a cull of the larger species of kangaroos, which compete with sheep and cattle, although no price support is needed.

For a cull to be implemented through a hunt by ordinary sealers, the following conditions would have to apply:

- The total impact of seals on fisheries from all causes combined must be substantial.

- The benefit to fisheries per seal killed must be greater than the cost per seal of the operation, which would be the additional price per skin paid to the sealers over and above the open-market price. Taking account of uncertainties, the requirement, in practice, should be that the additional support per skin be less than the lower limit of the likely benefit per seal killed.

- There should be general public acceptance that the net benefits of such an operation are sufficiently large to justify killing seals. In this context the net benefits should be taken to include any social and economic benefits accruing to the sealers.

Needs for Research

It is clear that if control of seal populations is to be contemplated, either immediately or as part of a long-term strategy, it must be supported by well-planned, comprehensive research programs. It would be particularly important to ensure that control activities are themselves seen as experimental and as major sources of data. Reliable data should be recorded on all aspects of the control activities themselves, including the number, sex, date and location of all animals killed. In addition, the effects of the program should be monitored; this monitoring should cover, in particular, the size, structure and distribution of the seal population, possible changes in its food composition, and the incidence of nematode parasites in key species of fish in the vicinity. This last investigation should take particular account of incidence in the younger age groups of fish.

There is also need to provide a sound basis for the development of population-control programs by means of vigorous continuing research on the underlying problems. These include:

- the size, potential for growth, and factors regulating the seal populations;
- the interactions between the seal populations, and the stocks of commercially important fish and invertebrates and the sizes of commercial catches;
- the relation between the size of the various seal populations and the level of infection of nematode parasites in commercially important fish on a local, as well as an overall, level;
- the relation between the infection rate of parasites in commercially important fish, the operating costs of the processors, and the marketability of fish.

More details on the research programs required are given in the chapters on the individual topics and in Chapter 30.

Summary

1. A number of organizations urged the need to limit or reduce seal numbers in order to minimize costs to the fishing industry caused by reduction of fish stocks by seal predation, damage to fishing gear and catches by seals, and need to remove nematode parasites from fish prior to marketing.

2. A number of other organizations stated in evidence that they were opposed to any control of seal populations, either as a matter of principle, that seals should not be killed to provide economic benefits to the fishing industry, or because impacts of seals on fisheries are not sufficiently well established to justify control measures.

3. Previous control operations have been for:

   - grey seal: culling, 1967–83; bounty, 1976–present.
   - harbour seal:

- east coast; bounty to 1976, since then by permit.
- west coast; bounty to 1964.

• Steller sea lion: periodic culls on rookeries, 1912–1966.

4. In order to achieve acceptable standards of humaneness, any control operations which may be undertaken should, if possible, be carried out by trained and responsible people, working under DFO supervision. The operations discussed which are most likely to be acceptable in this respect are killing grey seal pups either by clubbing or by shooting, Steller sea lion pups by shooting, and harbour seals by shooting.

5. Accurate records should be maintained of numbers of animals killed in any control operations, and biological material should be collected to enable changes in the age and sex structure of the population to be monitored. Hunting by government employees should provide the most accurate records of numbers killed. Past culling operations on breeding grounds, such as those for grey seals, provided biological samples which were not representative of the population, since the kill was mainly of pups and mature females. Bounty hunting or properly representative killing by government hunters could be more satisfactory in this respect.

6. The only species of seals for which the Royal Commission received recommendations for population control were harp, grey and harbour seals, and Steller and California sea lions. The hooded seal has a relatively large biomass and therefore consumes a relatively large amount of food, but it is believed to feed largely outside areas of interest to Canadian fisheries. The northern elephant, ringed and bearded seals have negligible impacts on commercial fisheries. The northern fur seal has some impact on the salmon and herring fisheries, but its numbers are declining at present.

7. Rough estimates of the total losses caused by each species of seal are given in Chapters 24, 25 and 26, and from these estimates the average impact of an individual seal of each species has been calculated. In the Atlantic these losses ranged from $40 or less for harp seals and a figure in the low hundreds of dollars for harbour seals to $900 or more for grey seals. Corresponding figures for the Pacific coast have not been calculated. The average impact is the total amount of losses which would be prevented if all seals were removed divided by the total number of seals. It is not necessarily equal to the reduction in loss that would be achieved if only one seal were removed; this is

called the marginal impact. The marginal impacts may sometimes be less than the average losses per seal, possibly considerably less in the case of losses caused by parasites. If a population were to be reduced, but not totally removed, the average benefit per seal killed would generally be intermediate between the overall average benefit and the marginal benefit.

8. Estimates of the costs per seal killed in control programs have ranged from about $10 for a large cull of grey seals proposed by the Task Force on Seal Borne Parasites (Canada, DFO, 1983), to $100 for adult seals killed for the bounty.

9. The effect on the seal population, and therefore on the impact on fisheries resulting from culling a seal, will extend for several years after the seal is killed. The extent of the effect on the seal population will vary with the characteristics of that population, and the effect on the present value of the impact will depend also on the rate at which future losses and costs of killing are discounted. For likely values of population parameters and of the discount rate, the net present value of the benefits per seal killed appear to be about three to nine times the marginal damage caused by one seal.

10. In addition to the economic benefits and costs outlined above, any decision to proceed with a cull must take account of the social costs and values associated with the existence of seals and of the public attitude to possible killing operations.

11. If it is decided to kill seals to maintain the population at some target level, a number equal to the sustainable yield will have to be killed. If it is desired to reduce the population, this reduction will require an additional kill in one year or spread over several years, over and above the numbers killed to keep the population at its current level.

12. No methods of killing other than shooting and clubbing, as practised in the past, seem to be suitable for use in control operations. The possibility of using the pistol proposed by Hughes (1985) for use in the harp seal pup hunt should be considered if there seems to be a strong economic case for controlling harp seal numbers by killing pups. (See Chapter 20.) Further research on means of driving seals away from critical areas should be encouraged.

13. In control operations the advantages of diffuse operations conducted by small teams of highly trained hunters as an alternative to mass killing on breeding grounds should be considered. The advantages include:

- maintaining the population structure;
- availability of more representative biological material;
- less environmental disturbance;
- the possibility of greater public acceptability.

14. If a major killing operation is carried out, every effort should be made to use carcasses and pelts. This would avoid waste, reduce environmental damage, reduce public reaction and, possibly, reduce the costs of the operation.

15. The marginal impact per harp seal is especially poorly estimated. Because the total numbers of this species are large, the total impact could be considerable. However, the marginal impact per seal could be very small. Although harp seals are increasing in number, the economic justification for an immediate cull of harp seals is, on present evidence, weak. Further evidence could change this conclusion, and more research on food habits, and the extent of parasite infection, is urgently needed.

16. The marginal impact of the grey seal is high, quite likely over a thousand dollars per seal. The benefits from a grey seal cull would almost certainly be several times greater than the costs even if the culling were done in a relatively expensive manner (i.e., on older animals away from the breeding grounds). Grey seals are increasing fairly rapidly, and if no culling is done, the problem perceived by the fishing industry will worsen. There is little information about the public attitude to a cull of grey seals.

17. On the Atlantic coast, the marginal impact of harbour seals is intermediate between that of harp and grey seals. The number of harbour seals is increasing only slowly so the problem is not becoming rapidly worse. On the Pacific coast, harbour seals are increasing rapidly and may have a considerable impact on the herring and salmon fisheries. However, a significant proportion of the damage caused may be attributable to a relatively few seals living near vulnerable

points. These may be better dealt with by means other than a general cull. This may also be true concerning damage by harbour seals on the Atlantic coast.

18. The economic impact of Steller sea lions has not been estimated but, in total, seems likely to be small compared to the impacts of Atlantic coast seals; competition for salmon seems likely to be much the most significant component. The population is probably at a lower level than at some time in the past and is not likely to be increasing. No cull appears justified at present, but population trends should be monitored. California sea lions are only present in B.C. waters for part of the year and probably eat few salmon. No action is justified at present.

19. Decisions on any population-control programs should be based on specific management goals which take account of social and economic values and have been reached by a process of wide consultation. To provide a basis for establishing such programs, vigorous continuing research is required on:

    - population dynamics of seal populations;
    - interactions between seal populations, and the fish stocks and commercial catches;
    - relations between seal populations and the intensity of nematode infections in fish;
    - relations between infection rates of nematode parasites in fish and resulting costs and losses to the fishing industry.

    This research would require both continuation of existing programs (e.g., relating to the harp seal population) and establishment of new or substantially expanded programs (e.g., relating to food of seals, relation between seal populations and nematode parasites, and relation between parasite incidence and losses).

20. All population-control programs should be treated as experimental and accompanied by careful monitoring not only of the program itself, but also of the effects on the seal population, its feeding habits, and the incidence of parasites in both seals and fish.

Conclusions

1. Seals cause financial losses to the fishing industry through competition for fish, damage to gear and catches, and contamination of fish with nematode parasites.

2. The species of seals differ considerably in their impact and in how the impact might change in the future.

   - Ringed, bearded, and northern fur seals probably have at most very small impacts.

   - Hooded seals may cause some losses due to competition for fish, but it is possible that their main feeding grounds are too deep and too far north for hooded seals to constitute a serious threat to Canadian fishermen.

   - Harp seals seem to have, at present, an impact only through competition for commercial fish; this impact could be significant. In the absence of a hunt the harp seal stock will increase. The effects due to competition and perhaps also damage to gear or transmission of parasites may possibly increase to the level at which they have serious impacts on the fishery.

   - Grey seals, which are increasing rapidly, are the major source of infection with parasites, and also probably contribute significantly to the losses due to competition, and to gear damage. These impacts are estimated to be between $60 and 115 million annually. Though far from precise, these estimates are known with greater precision than is the case for harp seals.

   - Harbour seals on the Atlantic coast cause losses that are very small compared with those due to grey seals; in addition, the population is expanding only slowly, if at all. On the Pacific coast harbour seals are increasing quite rapidly, and appear to cause significant losses of herring and salmon. On both coasts damage seems to be localized near seal colonies and areas of fish concentration.

   - Sea lions may have a small impact due to the effects of competition and damage to gear, although some of these losses may be highly visible.

3. These losses could be reduced, or at least prevented from increasing, by reducing or stabilizing seal populations. Based on present information, the only effective method of controlling the numbers of seals is through a cull, though other methods cannot be completely ruled out. For some seals the financial savings from such actions could be several times greater than the costs involved. If the seal stocks are increasing, as is the case for harp and grey seals, there would be disadvantages in postponing a cull if control measures are desirable. The longer a cull is postponed the greater the impacts on fishermen and the larger the numbers that would ultimately have to be killed.

4. In some circumstances the extent of the impact can be reduced without affecting the seal populations. The damage to fixed gears or aquaculture establishments may be reduced if effective methods of scaring seals away from these operations can be developed. It may also be possible to develop cheaper techniques for detecting and removing parasites from fish fillets.

5. There are considerable uncertainties about the magnitudes of many of these impacts, especially in relation to the effects of competition. There are also very large uncertainties concerning the extent of the changes in the impacts, especially the impact of parasites, that would result from changes in the numbers of seals. These changes are unlikely to be exactly proportional.

6. In view of the many uncertainties about the costs and benefits of population control, any such operations should be regarded as experimental and be supported by an expansion of relevant research programs.

7. Operations by government-employed hunters are generally superior to a bounty scheme on the basis of their effectiveness in meeting the objectives of the cull, their better collection of data on the kill, their lower cost and the greater humaneness of controlled operations.

8. Where seals cause serious local losses which cannot be prevented in other ways, consideration should be given to allowing fishermen to kill "nuisance" seals under strict controls.

9. Public attitudes towards killing seals, and regarding the relative values of seals and commercial fisheries, should be taken into account before any decisions on culling are made.

10. The chosen balance between the interests of fishermen and the views of those opposed to any killing of seals needs to be expressed in explicit guidelines for each seal population, determining whether they should be allowed to increase, be reduced or be stabilized.

11. For only four species – harp, grey and harbour seals and Steller sea lions – do current total impacts, or marginal impacts per seal, appear sufficiently large to make it necesary to consider measures of population control.

    For harp seals the present marginal impact per seal may be quite small, and might possibly be less than the cost of a government-operated cull. Large numbers would need to be killed for effective control, and there are many uncertainties that might be significantly reduced in a few years if there is an effective research program. A government-operated cull does not appear justified at the present time.

    The net economic benefits of a cull of harp seals would be greatest if it were carried out by existing sealers under a program of price supports for sealskins. In addition, such an operation would help to relieve some of the economic and social problems being felt in the traditional sealing areas. A large-scale cull of this kind would, however, almost certainly involve very considerable public protest.

    For grey seals the economic benefits of a cull to the fishery would, even on conservative estimates, be several times the likely cost of a cull. Culls of grey seals were carried out in the years up to 1983 without significant public protest. About 7,000 grey seals would need to be killed annually in order to maintain the population at its present abundance. This is more than were killed in the pre-1984 culls. Culls of this magnitude would almost certainly require operations on Sable Island, and these might involve increased public protest.

    For harbour seals the total impact is relatively small, and the most serious effects concern limited areas. The problems might be resolved by allowing fishermen to kill "nuisance" seals under strict controls, or by localized government culls.

    For Steller sea lions, the damage through attacks on fishing operations tends to be relatively conspicuous; however, the greatest impact on the fishery is probably due to competition for salmon. Losses due to all causes seem to be small compared to those on the Atlantic coast.

The population is probably no greater than in 1913 and is not increasing. There seems to be no technical justification for instituting a cull at this time, although it will be necessary to keep a watch on population trends.

Recommendations

1. The Department of Fisheries and Oceans should, with appropriate advice, establish explicit guidelines for determining which seal populations should, in principle, be allowed to increase, or be reduced or stabilized. No population control activities should be undertaken unless clearly favoured by the balance of social and economic benefits, and then only under a carefully monitored long-term program of evaluating their efficacy.

2. Any population control operations should be done under government supervision.

3. Fishermen operating fixed gears, including aquaculture establishments, may be given licences to kill "nuisance" seals in the vicinity of their gears under strict controls, with provision for a recompense for return of biological material of value to research programs.

4. Any population control programs should be:

   - designed to provide detailed data on such matters as the number, age, sex, location and parasite load of the animals killed, and

   - associated with continuing monitoring of the population concerned to determine any changes in the numbers, structure and principal biological parameters of the population, as well as the efficacy of the population control measures.

5. The government should promote further studies aimed to establish more precisely the impact of seals on fisheries through competition, damage to gear, and transmission of parasites. Particular attention should be given to the relationship between changes in seal numbers and changes in impact, especially in relation to parasites. Research programs should also be undertaken to determine the effects of any control operations, both on the seal populations and on their impacts.

6. Studies should be made of possible methods of controlling the abundance of seals, other than by culling. Studies should also be made of possible methods of reducing impacts other than by a general reduction in seal numbers. These might include seal-scaring devices and improved techniques for detecting and removing parasites.

7. There should not be a cull of harp seals in 1987, but the impact of harp seals on fisheries will increase, and the possibility of a cull in later years must be seriously considered.

8. If a cull of harp seals is found to be biologically and economically desirable and publicly acceptable, consideration should be given to the use, in the implementation of the cull, of ex-sealers from the communities most severely affected by the collapse of the seal markets.

9. The Royal Commission believes that biological and economic considerations indicate that substantial advantages would be gained by a cull of grey seals. Nevertheless, before deciding whether to implement such a cull, the Canadian government should take account of public opinion and should make use of the advisory processes discussed in Chapter 30 for this purpose. Because grey seals are increasing rapidly, a decision needs to be made as soon as practicable.

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Chapter 30

Canadian Management Policies

This section reviews Canada's record of managing seals and sealing and proposes future management policies. Some of the details of past management measures are considered elsewhere. The conservation of harp and hooded seals is described in Chapter 21, the control of possible cruelty in any large seal hunt in Chapter 20, and management of grey and harbour seals and sea lions in Chapter 29. A summary only of relevant measures is included here. The evaluation of past performance pays particular attention to two matters on which there has been criticism: lack of responsiveness and excessive costs.

Past Management Practices: Harp and Hooded Seals

Conservation

Harp and hooded seals migrate between Canada and Greenland. Until Canada introduced its 200-mile limit, much of the harvest was taken outside Canadian jurisdiction. In addition to the seals caught by Canadian sealers, substantial numbers of these animals were taken from both the Front and Gulf herds by Norwegian and other sealers. Significant subsistence hunting also takes place in Greenland.

Under such circumstances, co-ordinated international action was needed to manage the stocks. Until all the member countries of the International Commission for the Northwest Atlantic Fisheries (ICNAF) agreed to give it the power to deal with seals, a concurrence reached in 1966, regulations were largely confined to opening and closing dates. These were implemented by Canada unilaterally, though often after consultation with Norway. Beginning in 1971 quotas have been applied, first by ICNAF and, after the extension of jurisdiction, by Canada, acting on advice from the Northwest Atlantic Fisheries Organization (NAFO). The history of the specific regulations is summarized in Table 30.1 (for harp seals) and Table 30.2 (for hooded seals).

Table 30.1
Highlights of Management Measures Implemented for Harp Seals, 1961–1985

1961	Opening and closing dates established for Gulf and Front areas.
1964	Licensing of sealing vessels and aircraft.
1965	Prohibition on killing of adult seals in breeding or nursery areas; introduction of licensing of sealers, quotas in the Gulf, and regulations defining killing methods.
1966	Ammendments to licensing, extension of Gulf quota areas, rigid definition of killing methods.
1971	TAC for large vessels set at 200,000 animals; allowance of 45,000 for landsmen.
1972	TAC reduced to 150,000 (including estimated catch of 30,000 by landsmen).
1976	TAC reduced to 127,000.
1977	TAC increased to 170,000 (including allowance of 10,000 for northern aboriginal people). Number of adult harp seals restricted to 5% of catch.
1978	TAC increased to 180,000 (including an allowance of 10,000 for northern aboriginal people).
1980	TAC continued at 180,000 (including an allowance of 1,800 identified for the Canadian Arctic and 10,000 for Greenland).
1981	TAC for Canadian waters set at 170,000.
1982	TAC for Canadian waters increased to 186,000 (including an allowance of 11,000 for the Canadian Arctic).
1983–1985	TAC continued at the 1982 level.

Source: Canada, DFO (1985, Appendix IV).

TAC = Total allowable catch.

Table 30.2
Highlights of Management Measures Implemented for Hooded Seals, 1965–1985[a]

1965	Hunting banned in the Gulf of St. Lawrence.
1966	ICNAF assumed responsibility for management advice for northwest Atlantic.
1968	Open season defined as 12 March to 15 April.
1974	TAC set at 15,000 animals; opening and closing dates defined as 20 March to 24 April.
1975	TAC set at 15,000.
1976	TAC of 15,000 retained; opening date delayed to 22 March, shooting of seals banned between 23:00 and 10:00 GMT up to 31 March, and between 24:00 and 09:00 GMT thereafter (to limit loss of wounded animals).
1977	TAC of 15,000 retained; number of females to be killed limited to 10% of the total catch; shooting of seals in the water prohibited (to reduce loss by sinking).
1978	TAC of 15,000 retained; catch of adult females reduced to 7.5% of the total catch.
1979	TAC of 15,000 retained; catch of adult females reduced to 5% of the total catch.
1980	TAC of 15,000 and 5% limit on breeding females retained.
1981	TAC of 15,000 and 5% limit on breeding females retained.
1982	TAC of 15,000 and 5% limit on breeding females retained.
1983	TAC reduced to 12,000; previous conservation measures retained.
1984	TAC reduced to 2,340; previous conservation measures retained.
1985	TAC of 2,340 and other conservation measures retained.

Source: Canada, DFO (1985).

a. TACs as listed refer to total allowable catch in Canadian waters.

Apart from measures specifically directed at the conservation of stocks, a number of other regulations were introduced during the same period. In part they dealt with the administrative machinery needed to make the catch limits effective. Other regulations controlled the methods of killing and were directed at reducing the degree and frequency of any suffering inflicted on the seals. The chronology of these regulations is set out in Appendix 30.1.

How successful has been the Canadian management of harp and hooded seals, as measured against the objectives it was presumably expected to achieve? An immediate difficulty, particularly as far as conservation is concerned, is that for much of the period the objectives were only qualitative. Thus, in its brief to the Royal Commission, the Department of Fisheries and Oceans (DFO) declared as its current policy:

> *...that seals are considered a natural renewable resource available to be humanely harvested within the limits of sound conservation principles, taking into account its role in the ecosystem, with the object of gaining the maximum socio-economic benefits for Canadians in general, and those who depend directly on the resource in particular. This policy reflects a shift in 1976 from previous policies designed to achieve maximum sustainable productivity (Canada, DFO, 1985).*

A quantitative objective was set in November 1978, when the European Community (EC) and Canada agreed to set an interim target population of 1.6 million harp seals aged one and older (Canada, DFO, 1985, p. 5). This objective, however, no longer seems to be followed.

The degree of success in achieving either maximum sustainable productivity (presumably roughly equivalent to maximum sustainable yield (MSY)), or a broader socio-economic objective, which must require a reasonably high sustained catch, can be judged from the history of the stocks reviewed in Chapter 21. In brief, it can be said that in the period from 1950 to the mid-1960s, these objectives were not achieved, and the stocks declined.

The blame for this mismanagement does not lie wholly with Canada. Canada had control only over Canadian sealers, but substantial catches (often amounting to well over half the total) were taken by vessels from other countries operating in what, until 1977, were waters outside any national

jurisdiction. Norway has been much the most important foreign country in the sealing industry, but since 1945, single vessels under the registry of Denmark, France, the United States and the U.S.S.R. have taken seals (Sergeant, 1965). Although ICNAF had responsibility for fisheries in the international waters of the northwest Atlantic since 1949, it gained authority to deal with seals only in 1966. The legal setting of seal management changed again in 1977, when both Canada and Denmark (in behalf of Greenland) established 200-mile fishery-management limits, which meant that harp and hooded seals could no longer be caught in the western Atlantic outside the jurisdiction of one or the other coastal state.

Since the 1971 season, when the quotas set by ICNAF in 1970 came into effect, the numbers of seals that can be caught have been limited by quotas which, since 1977, have included allowances that took account of unregulated catches by the aboriginal population in Greenland and northern Canada. Tables 30.3 and 30.4 indicate that, with minor exceptions, the regulations have been successful in keeping catches within the annual quotas.

The details of these quotas, and the effect that they have had on the stocks, are discussed in Chapter 21. In brief, it is clear that the quotas did stop the serious decline in harp seal stocks that had been in process. They probably did allow the stocks to increase, though the possibility of a small decrease cannot be ruled out on the basis of an analysis done for the Royal Commission (Cooke et al., 1986). The most recent analysis (Roff and Bowen, 1986), however, presents evidence of a substantial increase in the maturing stocks aged two to six years.

The situation concerning hooded seals is less clear, but it is more probable than not that average catches since 1972 have been below the replacement yield, and that the stocks have been increasing.

Judged against the broadest target, that of maintaining a productive stock, management since 1972 has been successful for harp seals and probably also for hooded seals. The only qualification of this assessment would be the slight possibility that one or other stock has been declining. The Royal Commission believes, however, that even if such a decline had been occurring, the existing management system, including the programs of monitoring and research, would have been sufficient to detect and reverse the decline before it became serious.

Table 30.3
Harp Seal Quotas and Catches in Canadian Waters

	Total Allowable Catch	Catch		
		Canada	Norway	Total
1971	245,000	132,660	98,306	230,966
1972	150,000	76,583	53,300	129,883
1973	150,000	65,542	58,290	123,832
1974	150,000	92,050	55,585	147,635
1975	150,000	114,202	60,161	174,363
1976	127,000	119,519	45,483	165,002
1977	170,000 [a]	119,519	35,624	155,143
1978	180,000 [a]	145,469	16,254	161,723
1979	180,000 [a]	140,253	20,288	160,541
1980	180,000 [b]	149,313	20,213	169,526
1981	183,000 [c]	175,450	22,382	197,832
1982	186,000 [d]	142,501	24,238	166,739
1983	186,000 [d]	57,889	–	57,889
1984	186,000 [d]	30,900	–	30,900
1985	186,000 [d]	17,723 [e]	–	17,723 [e]

Source: ICNAF/NAFO (1971–1984); Canada, DFO (undated, 1986).

a. Including an allowance of 10,000 for northern aboriginal peoples.

b. Including an allowance of 1,800 for the Canadian Arctic and 10,000 for Greenland.

c. Including an allowance of 1,800 for the Canadian Arctic and a forecast catch of 13,000 for Greenland.

d. Including an allowance of 11,000 for the Canadian Arctic.

e. Preliminary data for Newfoundland and Quebec only.

Table 30.4
Hooded Seal Quotas and Catches in Canadian Waters[a]

	Total Allowable Catch	Catch		
		Canada	Norway	Total
1971	–	432	14,514	14,946
1972	–	422	12,178	12,600
1973	–	312	6,255	6,567
1974	15,000	204	9,796	10,000
1975	15,000	5,385	10,226	15,611
1976	15,000	3,867	8,518	12,385
1977	15,000	6,044	6,049	12,093
1978	15,000	4,189	6,315	10,504
1979	15,000	6,819	8,306	15,125
1980	15,000	7,409	5,707	13,116
1981	15,000	8,309	5,367	13,676
1982	15,000	5,831	4,562	10,393
1983	12,000	128	–	128
1984	2,340	444	–	444
1985	2,340	452	–	452

Source: ICNAF/NAFO (1971–1984); Canada, DFO (undated).

a. Figures exclude research catches.

In relation to more specific and more rigorous targets of achieving MSY or an interim stock of 1.6 million harp seals, the evaluation is less clear. The total (late 1985) population of harp seals one year of age and older is probably not far from 1.6 million, and may well be in excess of that figure, though the possibility of its being a little less cannot be ruled out. It is far from clear what population abundance would give MSY, either in actual numbers or as a percentage of the original, unexploited population, and it is also possible that human exploitation of capelin and other species which the seals

eat could have reduced the population level required to give MSY under existing conditions. On balance, it is probable that the present stocks of both harp and hooded seals are below the MSY level corresponding to current environmental conditions.

Before concluding on this basis that management has been unsuccessful, two points would have to be made:

- Given that the stocks in 1970 were well below target levels, they could not be restored to those levels instantaneously.
- Neither the target of 1.6 million older seals nor that of MSY was ever unanimously accepted.

On the first point, the rate at which a depleted stock is rebuilt must usually be a matter of judgment that balances greater long-term benefits from a rapid rebuilding against the disruption to the industry likely to arise from the drastic measures required. Theoretical studies (e.g., Clark, 1976) suggest that, under certain assumptions, the greatest long-term economic benefits occur when the stocks are rebuilt as rapidly as possible. This is achieved by stopping all harvesting until the stocks have recovered to the target level. The International Whaling Commission (IWC), under its New Management Procedure, requires catches to be set at zero unless the stock is above, or only very slightly below, the MSY level.

Serious economic problems may not occur when the industry has alternative resources to harvest during a rapid rebuilding period. In this situation, a complete moratorium, such as the six-year one recommended by the Committee on Seals and Sealing (COSS, 1971) might be practical. It has the advantage of being easier to enforce than is a reduced catch. Most sealers, however, have no alternative resources during the sealing season and a moratorium would cause serious difficulty for them. Some catch, even if small, is preferable on social and economic grounds to zero catches for a period, followed by a major hunt. In the Canadian situation, therefore, it does not appear on purely economic grounds that the preferred speed of achieving the target population should be the fastest possible, brought about by a complete cessation of hunting. The actual speed of the process has to be a matter of choice, and there is little evidence to suggest that the speed that was being achieved in the late 1970s and early 1980s was either too fast or too slow.

On the second point, the weaknesses of MSY are reviewed in Chapter 27, and in Chapter 29 evidence is presented on gear damage, competition and

the spread of parasites from seals to fish, showing that for the Canadian fishing industry a small seal population would be desirable. It is far from clear what the optimum population of harp or hooded seals should be. That figure will almost certainly depend largely on the balance among the different factors considered above.

Humaneness

An important aim of management has been to reduce the cruelty involved in sealing. Most of the measures introduced in the mid-1960s concerning the types of club or hakapik allowed and the way either implement could be used related to this objective. There seems little doubt that these measures have significantly reduced the amount of suffering. (See Chapter 20.) It appears, however, that not all sealers always comply with the regulations. In 1981, as a result of unusual ice conditions, seals came close to the coast of Prince Edward Island and a number of inexperienced landsmen took part in the hunt, some of whom did not use proper killing methods. This hunt, however, was closed down quickly when the federal authorities became aware of its non-conformity with regulations, and measures have been taken to prevent a repetition.

The extent of irregular methods in the main commercial hunt in recent years is unclear. The general impression from the information available is that enforcement of the sealing regulations improved during the late 1960s. It has since been generally effective, although there have been some exceptions. (See Chapter 20.) Unfortunately, the degree of distrust between the anti-sealing groups and the federal authorities remains great. Fishery officers and other authorities have devoted much time and energy to controlling the efforts by some protest groups to disrupt sealing operations. It is, perhaps, understandable that fishery officers, often themselves from sealing communities and familiar with local conditions, react as they do to the more extreme protest groups. It would not be surprising if, in some instances, they may have given more attention to enforcement of the laws against interference with the hunt than to enforcement of those concerning the activities of sealers.

Whatever its shortcomings, Canada's record of improving the humaneness of the commercial pup harvest is reasonably good. Hunting of seals older than pups, for both commercial and subsistence purposes, is carried out largely by shooting. The humaneness of this type of sealing has not been raised as a major issue.

Other Issues

From the preceding sections it appears that, measured against the requirements to conserve the stocks and to minimize any cruelty, Canada's record in the last 10 to 15 years, since there has been authority to apply measures over all the seal hunt, has been good. There have been shortcomings, but of no greater dimensions than those that have occurred in many similar situations of natural-resource management.

Nevertheless, Canada has come under very severe criticism for its stewardship of harp and other seal stocks, perhaps more severe than any other similarly responsible authority with the exception of the IWC. Some of these criticisms have been misplaced, based as they were on misconceptions, or applicable to the situation prior to the mid-1960s, rather than to current practices. Two substantive points have been made, however, that do merit examination: those of responsiveness and of excessive costs.

Responsiveness

At the technical level, the responsiveness of the Canadian authorities to scientific advice has been good. The quotas set have closely followed the recommendations of responsible scientific advisers. Similarly, the controls on methods of killing have largely conformed to the proposals of technical advisers.

It may be objected that these sets of advice came primarily from scientists employed by the management authority. For example, a large number of Canadian government scientists were on the ICNAF and NAFO committees. It is doubtful whether this circumstance made much difference to the substance of their advice. The conclusions concerning harp seals reached by the International Council for the Exploration of the Sea (ICES, 1983) and the United Kingdom's Nature Conservancy Council (NCC, 1982) groups, which were of very different composition, were similar to those reached by the ICNAF and NAFO committees.

One area in which valid criticisms can be raised, however, relates to the emphasis given to different interpretations of results when the basic analysis is inconclusive or ambiguous. The Canadian management authority has tended to act on the more optimistic interpretations. In this sense, it has been unresponsive to the general line of conservation thought as expressed, for example, by Holt and Talbot (1978), that in cases where there

is doubt, management should act on the more pessimistic interpretations of available data.

Criticisms of DFO on this point, in fact, are more relevant to the words of the Department and its apologists than to its deeds. There have been occasions, most noticeably in connection with the ICES report, when official Canadian statements, in claiming justification for Canadian policies, have chosen the optimistic interpretation of the results. (See Chapter 9.) Actually, the ICES report, to use that document as a convenient example, did provide good support for past Canadian actions.

Although quotas, and other policies, have not been set according to the most conservative interpretation of the data, neither have they been set at the other extreme. Quotas have generally been consistent with the central values of replacement yield, to take one example, and subsequent history does not suggest that they have erred significantly on the high side.

Criticism of Canadian management authorities for their lack of responsiveness has much less to do with technical issues than with basic policies. The central issue is whether or not the hunt (especially the white-coat hunt) should continue. The official Canadian position consistently has been that the seal hunt is a legitimate activity which, subject to controls for reasons of conservation or humaneness, should be allowed to continue. Rather than emphasizing as formerly the inhumane treatment of seals or the danger to stocks, the anti-sealing forces have now begun to object to sealing *per se*. The different categories of complaint are often confused or combined so as to strengthen the impression that there is a broad-based opposition to the hunt. (See Chapter 9.)

Whatever the grounds used for opposing the hunt and however receptive the public may have been to the anti-sealing appeals, it must be admitted that the Canadian authorities have not responded effectively. There has been no attempt, until now, to re-examine basic policy and the public response to that policy. At present, national policy is not consistent with the apparent public attitude towards sealing. If, on the one hand, public attitudes are strongly held on the basis of correct information, it would appear desirable to modify policy. If, on the other hand, the opposition to sealing is more apparent than real or, if real, has been based on misinformation or misunderstanding about sealing, it would be desirable to do more to inform the public and to determine what its attitudes really are. In a matter like sealing, which catches the public eye and arouses great public interest, but of which the public as a whole has no direct experience, it is as

important to keep the public adequately informed as it is to respond to apparent public attitudes.

Costs

The costs incurred by the Canadian government in connection with the seal hunt have included the following:

- biological research;
- direct support to sealing operations (e.g., assistance by ice-breakers);
- policing of regulations on the sealing grounds;
- general administrative activities.

It has been alleged that the total costs of these activities have been too high and that they may even have exceeded the value of the seal harvest.

Not all these costs are easy to determine because several of them involve general activities of the Department of Fisheries and Oceans, which would be carried on even if there were no sealing. The best available data on DFO costs are those provided in a letter from the Deputy Minister, dated 18 June 1985. This letter gave figures for the savings in the 1982 expenditure that might have been achieved if there had been no seal hunt; it included some estimates of additional costs incurred by the Ministry of Transport and the RCMP (Table 30.5).

It was explained that in some cases the potential savings in 1982 were different from the regular annual savings that might be achieved if sealing were stopped permanently. Thus the potential for savings connected with research in 1982 was less than the potential longer-term savings because much of the seal-related research could not be phased out immediately. The potential savings on publicity in 1982 were unrealistically large because, it was stated, the advertising campaign that took place in 1982 would not have been a regular annual expenditure. This statement may represent an optimistic view.

Biological research on seals is obviously important and would remain important even if the whitecoat hunt or other sealing enterprises were to cease. To find the answer to many questions important for the ordinary commercial fisheries requires research, especially concerning the competi-

tion for fish between seals and fishermen and the interrelationship between the various species of seals and parasitic infection of fish. In Chapter 29, the Royal Commission has recommended that research on these matters should be increased.

Table 30.5
Estimated Non-Expenditure in Absence of Seal Hunt

Activity	Savings in 1982[a]	Regular Annual Savings
Research	$137,000	$247,000
Surveillance (by DFO, RCMP, MOT)	295,000	295,000
Ice-breaking	Nil	Nil
Publicity and public relations	240,000	50,000
External Affairs	5,000	5,000
COSS	60,000	60,000
	$737,000	$657,000

Source: May (1985a, 1985b).

a. Savings in 1982 were considered different from "regular annual savings" because of special expenditures in 1982 and inability to phase out research immediately.

Even when one considers only the "intrinsic" value of the seals and the public interest in them, the present level of government-sponsored research appears to be fully justified. Matched against the total value of the relevant fisheries (for cod, capelin, flounder and other species), the costs of research appear small and well justified. The Royal Commission believes that research is vital for the wise management of any wildlife stock, even if the directed harvest is minor. Specifically, the Royal Commission believes that the current level of research into seals is barely adequate, and that the cessation of commercial sealing would not provide justification (or excuse)

for reducing current research expenditure. In other words, the suggested savings in research in the absence of sealing may be unrealistic.

To estimate zero additional costs to government for ice-breaking also seems unrealistic. Some savings must result from the idling of ice-breakers, which in the past operated in sealing areas during early spring, but the Royal Commission was unable to obtain an estimate of such savings from DFO. Presumably, it was argued that ice-breakers would be engaged in some activity and incurring costs even if no sealing took place and that no charge was made to DFO for their services. A more comprehensive evaluation of costs should take account of the potential benefits to be derived from the alternative activities. These costs presumably would be less than the total costs of the ice-breakers, but certainly not zero.

The costs of enforcing the sealing regulations depends in large part on the degree to which sealers accept the regulations as reasonable. It has been pointed out that, given the nature of the hunt, it is impossible, without a very large enforcement staff, for patrol officers to be present at every point where a seal is killed. Under normal circumstances, such an intensive check should not be necessary. Most people obey reasonable laws without a policeman looking over their shoulders. No evidence has been put forward to suggest that many sealers deliberately set out to break sealing regulations, whether in relation to conservation (open seasons and quotas) or to humaneness (proper use of the specified club or hakapik).

Before the confrontational extremes between sealers and anti-sealers created an atmosphere of distrust, the sealing regulations probably could have been enforced adequately by fishery officers in the course of their general duties, and any additional costs would likely have been reasonable in relation to the value of the seal hunt. If the regulations are now difficult to enforce and require direct supervision of individual sealers, the situation has come about largely because of the lack of trust between sealers and elements wanting tighter control on sealing operations. The policing and surveillance costs do seem high in comparison with the value of the products, but a high percentage of the costs can be ascribed to the strong controversy over Canadian sealing. The Canadian government has had to make sure not only that the regulations are enforced, but that they are also seen publicly to be enforced. The authorities must also keep order between the protesters and the sealers. Both groups may be pursuing legitimate activities, but they do not co-exist easily without disorder unless authority is present in force. The high costs of enforcement of some one-third of a million dollars should not be intrinsic to any sealing operation, in the absence of controversy and ill-feeling.

Given that the Canadian government considers sealing a legitimate activity, it is a proper responsibility of the government to respond to a movement attempting to stop the seal hunt. In itself, therefore, it would not be a valid criticism of government policy to state that the total money spent in connection with sealing exceeds the value of the harvest, even if this statement were true, though it can be asked whether that money has always been spent effectively. This last question is valid whether the efforts are considered solely as a defence of the sealing industry or, perhaps more properly, as attempts to provide a balanced picture of the issues involved.

The appropriate question about government expenditure on publicity, therefore, seems to be whether it represents a reasonable or an unduly expensive response to the public relations activities of those working to stop sealing. This does not imply that an exact dollar-for-dollar equivalence in the two sets of activities would necessarily be desirable. The fact that the expenditures mentioned – even the peak figure of $240,000 in 1982 – are almost certainly much less than the public relations expenditures in the anti-sealing campaign (which are not well known) does suggest, however, that the former were not excessive. This assessment probably still would be valid if all government expenditures on public relations were included, for example, the activities of those officials in DFO and External Affairs, whose day-to-day workload during the past several years was dominated by the sealing issue, even if their duties were not specifically identified as being concerned with seals. It appears that the figures mentioned above cover only items which can be explicitly identified as dealing with publicity relating to seals, such as payments for advertisements. The true costs, especially to External Affairs, could be much higher than these figures.

A similar difficulty applies to the cost of support for sealing operations and to general administrative costs. The figures shown above indicate that the potential savings in these areas could be zero, excepting $60,000 for COSS. This seems unlikely, or at least suggests that 1982, the year on which the figures were based, was not typical. On the other hand, there is no suggestion that these elements of overall cost have been excessive. They may not have been small relative to the actual cash value of the harvest, but it is believed that high costs are almost inevitable for activities largely carried out in small isolated communities.

Admission of Observers

A further ground for criticism of the way in which sealing has been managed concerns the admission of observers to the sealing grounds. It has

been suggested that the Canadian government has influenced the balance of opinion among observers towards regarding the hunt as humane by refusing permission for certain observers to visit the hunt (e.g., W.J. Jordan cited in Charlton, 1980; Harrison, 1985). In 1978, it was made necessary to have a government permit to visit the hunt.

The government's reasons for rejecting requests for observer status at the seal hunt are unknown. (See Chapter 9). It should be noted, however, that many persons who have received permission to observe the hunt have represented organizations that were opposed to the hunt. For example, the World Society for the Protection of Animals (WSPA), which was formed by the 1981 union of the International Society for the Protection of Animals (ISPA) and another organization, is "in principle opposed to the taking or killing of wild animals or the infliction of any pain, suffering or injury upon them" and has called upon the Canadian government to abolish the seal hunt (T.H. Scott, 1985). WSPA and ISPA have worked for many years to eliminate cruelty from the hunt and have sent many officers to witness the hunt. Walsh (1985), who has been an observer of the hunt for ISPA/WSPA on at least 10 occasions, stated that he had "viewed nearly all aspects of sealing activities," and that he had "never been restricted from seeing any aspect of the sealing operations, and the helicopter was usually put at the disposal of the observers to land anywhere we chose."

The Royal Commission believes that government has a responsibility to ensure that citizens are permitted to go about their legal activities without serious hindrance from others who may dislike those activities, however worthy they believe their motives to be. In exercising this control of access, however, the government should take care not to exclude people who have the willingness and technical competence to ascertain the facts about events at the hunt, whether or not their views conform with existing government policy.

Other Seals

Northern Fur Seals

Management of this species had been the subject of international agreement between Canada, Japan, the United States and the U.S.S.R. until very recently. (See Chapter 22.) Direct Canadian involvement in fur sealing was minimal during the 70-year period of international agreement, but

Canadian participation in the North Pacific Fur Seal Commission was active and contributed to the success of that body. Suggestions are made elsewhere (Chapters 22, 28) for possible alternative arrangements to take account of the termination of the Fur Seal Commission and the changing situation in the north Pacific, but in any event Canada should continue her policy of active international collaboration.

Other Temperate-Zone Seals

Though there apparently has been a small commercial hunt for harbour seals along the north shore of the Gulf of St. Lawrence (Beck, 1983), the main concern of government policy relating to harbour and grey seals in the Atlantic and to harbour seals and sea lions in the Pacific has been with their possible effect on fisheries. (See Chapter 29.) This concern has led to a number of measures to control the populations of these seals, principally through the payment of bounties to fishermen or through government-implemented culls.

Between 1927 and 1976, bounties were paid to fishermen on the Atlantic coast for harbour seals. Bounties were also paid on harbour seals between 1914 and 1964 in British Columbia, where the seals were also subjected to a hunt organized by federal fishery officers, killed opportunistically by fishermen and, between 1964 and 1969, killed for their pelts. The grey seal has been subject to a cull, executed by DFO, from 1967 to 1983 and bounties have been paid on grey seals since 1976. In British Columbia sea lions have been subjected to a variable, and at times intensive, control program, at intervals during the period 1912–1966. This program included organized culling by fishery officers, bounties and a commercial hunt for the production of leather and mink food. Since 1970, all seals and sea lions on the Pacific coast, including harbour seals, have been protected, though it is not impossible that some seals or sea lions are killed illegally.

The details of these programs, and the effect they have had on the stocks, are discussed in Chapters 21 and 22. The rationale for them has generally been expressed, if it has been explicitly stated at all, in very general terms, such as "for control purposes to reduce interference with salmon fisheries" (Canada, DFO, 1985, p. 86), or because of the harbour seals' "supposed role in fish consumption, damage to fishing gear and transmission of cod-worm" (Boulva and McLaren, 1979). The programs mostly concern interference with fishermen, though an additional justification has been the scientific value of the data obtained. The DFO brief (Canada, DFO, 1985, p. 82) states that "Until the necessary resources are available to replace it with

an equivalent program the bounty system is necessary for population estimation and trend monitoring."

These programs must have kept seal numbers lower than they would have been in the absence of any cull or bounty kill. If they were intended to keep the seal population from increasing, the results must be considered mixed. Harbour seals on the Atlantic coast have been reduced and the bounty discontinued, but grey seals have increased in number, most notably on Sable Island. No seals from the Sable Island herd were killed there but some seals from this breeding ground might have been killed when they moved elsewhere. If the cull program was intended to reduce the grey seal population, it was not successful, although, presumably, it did do something to slow down the stock's increase elsewhere on the coast. In general, bounty and cull programs probably represent a response to pressure from fishermen for alleviation of a common nuisance.

Seals in the Arctic

The Canadian government has done little to manage seals in the Arctic. The DFO brief states that:

> *The DFO has recognized that maximizing economic benefits therefore must assume a lower priority in the Arctic seal hunt than do other objectives. To this end the Department has undertaken a low-level approach to regulatory management and has acted instead as stewards concentrating primarily on improving hunting practices through negotiations with HTAs [hunting and trapping associations] (Canada, DFO, 1985, p. 92).*

Even when the catches of harp seals were being controlled on their wintering and breeding grounds in the Gulf of St. Lawrence and off Labrador and Newfoundland, no controls were set on the summer hunt in the Arctic. Only after the quota system had been in force for some time were the arctic catches explicitly taken into account and quotas set on the basis of an estimate of the likely catch.

As mentioned in Chapter 13, the Royal Commission agrees with this hands-off approach and believes that the federal government should devolve as much authority as possible to the aboriginal peoples of the North. How-

ever, some backing from the federal authorities will probably be necessary in such matters as research and compilation of data. Although some statistics relating to annual seal catches are available, including data on the sales of skins, these appear to be inconsistent and incomplete.

Future Management Policies

Research

An adequate understanding of the system being managed is essential to successful management. Research into seals and sealing is therefore an important part of seal management. As noted earlier, Canada already has a strong tradition of high quality seal research, but the changes in the sealing industry and in the problems being faced will require changes in research priorities. More attention should be given to the interactions between seals and fisheries, particularly through competition for fish and the transmission of parasites. The details of the problems being faced and of the research required to solve them have been discussed in Chapters 24, 25, 26 and 29. Here we are concerned with bringing together the different research requirements and putting them in the context of the overall management program.

The questions to which managers need answers, and need research to provide the answers, are not confined to biological problems. More information is required, for example, on the relation between the frequency of parasites in fish flesh and the costs to the processing industry for removing them, and on the views held by the Canadian public on the killing of seals to protect fishery interests. More socio-economic information is also needed; for example, on the patterns of life in isolated sealing communities, on the effectiveness of many of the public services they are receiving, and on the economic options they either have or, with government intervention, could have. Many major research problems are biological. Therefore, without forgetting the need for other types of research, this section will focus on biological research.

The more pressing questions about the dynamics of seal stocks now relate to the possibility of increased effects on fish stocks. How fast are some stocks, especially those of grey and harp seals, increasing? If no control measures are applied, how long will they continue to increase, and how

numerous will they be when they cease to increase? Questions about the effect on seal numbers of killing seals still require an answer, but in addition to asking them in the form, "How many can be killed without reducing the stocks?", which still remains an important query for ringed seals, the questions are now more often, "How few need to be killed to prevent the numbers of seals increasing beyond some target level?" It is commonly assumed that killing seals is the only effective way of limiting total numbers of seals. This assumption is probably true, but studies of alternative methods of control, such as disturbing the breeding sites, should not be neglected.

Some established lines of research will continue to be important, particularly regular monitoring of the abundance of seal stocks by aerial surveys or other methods, whether the concerns are with seals as an exploitable resource or as a potential menace to fisheries. In addition, where there is concern about the extent of future increases in the absence of human control, more research will be needed into the density-dependent factors which provide natural controls, such as changes in age at maturity and mortality rates, the levels of population abundance at which these factors become effective, and the aspects of the environment, such as food supply, to which they may be linked.

In general it seems that, apart from hunting, the effect of human activities on seals is minor and that, for this reason, research on these topics does not require particular attention. There are, however, exceptions. It is highly desirable to know whether the decline in fur seals in the north Pacific is the result of entanglement with debris and, if so, what can be done to reduce it. If development is likely in the Arctic, more needs to be known about the possible impact of heavy ship traffic on ringed seals and the likely effect of oil spills or other forms of pollution on these and other seals.

Most research will need to cover more than seals. To explain the effect on fish stocks, more data need to be collected on the diet of seals, and how it varies seasonally and geographically, but these studies should be better integrated with studies of the dynamics of fish stocks. Special attention ought to be paid to the factors that might seriously invalidate the simple assumptions made in Chapter 24. Do seals, for example, in any way feed selectively on sick or especially vulnerable animals? Attention in the first instance should be focused particularly on grey and harp seals on the east coast, and on harbour seals on the east and west coasts, but better information is desirable on the diet of all seals that inhabit Canadian waters.

The study of the problem of nematode infection requires an even broader approach. Certainly more data need to be collected on the occurrence of parasites in seals. Much of what is available is old, and it is often based on very few animals. Information is particularly poor and old for harp seals. It would be desirable to know soon whether or not, under the changed conditions of harp seal numbers and nematode abundance, harp seals have become or might become a significant carrier of the parasite.

This collection of data on the occurrence of parasites in seals must be combined with much more extensive collection of data on the occurrence in fish, including the variation with time and place, and with age and size of fish. Both sets of data must be brought together into a study of the dynamics of the parasite itself, to provide a much better insight into how changes in seal numbers might affect the rate of infection, and whether other approaches to reducing infection in fish might be available.

Studies of the direct impact of seals on fisheries, through damage to nets or removal of fish from nets, probably require less in-depth research but, as in other forms of impact, more needs to be done to collect systematically from surveys of fishermen, for example, the basic information concerning the extent of the damage.

The Royal Commission has not attempted to detail the research required or to estimate the costs. However, as indicated earlier, it is highly unlikely that the costs of seal research can be reduced. With the decline of the commercial hunt, some lines of research, such as studies to obtain more precise estimates of the sustainable yield of harp seals, can be reduced, but others, such as those relating to competition, need to be intensified. Overall, taking into account the complexities of some of the problems, it is probable that the resources put into research on seals and seal-related problems will need to be appreciably increased. It will be important also for this research to be co-ordinated or integrated with related research, for example, on fish stocks.

The costs to Canada of the required research could be reduced through collaboration with other countries. In some instances, such as those relating to the decline of the fur seal in the north Pacific, collaboration is essential because of the nature of the problem. In others, such as the dynamics of the *P. decipiens* population, the similarities of the problem in different countries make it much more efficient for countries to collaborate by exchanging information and sharing in the costs of those types of research, such as the development of theoretical models, which are best done in a single place with good access to the necessary expertise.

Location of Responsibilities

The management of seals and sealing is currently the responsibility of the Department of Fisheries and Oceans. When the problems involved were largely those of orderly regulation of the sealing industry, and when seals could be considered, primarily or exclusively, a natural resource to be used in the same way as fish stocks and other natural resources, this arrangement was quite appropriate and caused no difficulties.

This situation no longer exists. Many individuals and organizations do not consider seals to be merely a natural resource, and they challenge the view that seals should be exploited largely according to economic criteria. To the extent that this opinion is that of a majority or of a significant minority in Canada, the appropriateness of DFO as the responsible management institution becomes questionable. This concern might be intensified if Canadian policies on seals have to deal to a growing extent with the interactions between seals and fisheries.

The issue is valid and, if management involved only the making of policy decisions, in which the viewpoint adopted can be important, DFO's fitness for sealing regulation would certainly be doubtful. Many other activities are involved, however, including the collection of basic information, research, the development of management strategies and tactics (program design), and the implementation of regulatory programs. If there were no commercial sealing, or if under no circumstances were seals to be killed, some of these activities might decline in importance, but research, at least, would always be necessary. As related to sealing, the activities mentioned fall naturally within the ambit of DFO. The collection of basic information, for example, although needed only if a sealing industry exists, is most efficiently done by DFO as part of the general work of collecting fishery data.

The emphasis in research relating to seals is changing and is likely to change further in the future. Ten years ago the key questions were, "How many seals are there?" and "What is the sustainable yield and how does it compare with current catches?" Answers have been obtained to these questions. Although they are not precise or final answers, and relevant work should continue, they are reasonably accurate. It is generally realized that management can and should operate with assessments that are subject to some degree of error, provided that policy is adjusted accordingly. In any case, with the collapse of the market for sealskins and the consequent reduction of the harvest, the questions referred to have become less urgent

and may continue to be low in priority for some time, especially if all or some forms of commercial sealing are prohibited.

At present, the more urgent scientific questions concern the various effects of seals on fisheries. If some or all forms of sealing are prohibited so that the numbers of seals increase substantially, the latter questions will become of pressing urgency. Research into such questions must be closely integrated with research on the fisheries and fish stocks and with more general research on the marine ecosystem. All these matters are handled by DFO. Similarly, the enforcement of regulations concerning commercial sealing, conducted mainly by persons who are commercial fishermen at other times of the year, is most readily done by the DFO field staff as part of their normal regulatory duties.

Under present conditions, therefore, only future policy issues would not fall naturally and conveniently within the jurisdiction of DFO. If, for example, a decision were taken to kill a certain number of harp seals in order to benefit fishermen, opposition by several environmental or animal-welfare groups might be expected and, if this decision were taken solely by DFO, it might well be open to grave criticism as being prejudiced in favour of the fishermen. Judging from experience in Scotland, in respect of a proposed cull of grey seals in the Orkney Islands, the opposition could reach a level that would seriously impede operation of the program.

To ensure that justice for the seals, as well as for fishermen, is not only done, but is seen to be done, and that DFO is removed from a potentially impossible position, decision making in this area of policy should be more broadly based. A possible arrangement to achieve that end is proposed in the following section. Provided that it or an equivalent arrangement can be implemented, the Royal Commission believes that the responsibility for seals and sealing, at least on the Atlantic and Pacific coasts, should remain with DFO.

The situation is different in the Arctic. No large network of local fishery officers capable of handling the day-to-day collection of statistical and other information exists in this region. Moreover, relevant research does not fall entirely within the scope of DFO's activities. In particular, an important scientific question highly relevant to the management of arctic resources is the interaction between ringed seals (a responsibility of DFO) and polar bears and foxes (a responsibility of the Government of the Northwest Territories with some research also carried out by the Canadian Wildlife Service). There are also important issues relating to the possibly heavy, year-round traffic through arctic ice-fields that may result from hydrocarbon and miner-

al development and its impact on the environment, including the breeding lairs of ringed seals. (See Chapter 23.)

While it is possible for good research to be done under divided jurisdiction, it is more likely to be done as part of an integrated program under a single authority. The information available was insufficient to enable the Royal Commission to make a specific proposal. It is probable, especially if research on seals and polar bears is part of a large-scale program of research and conservation in the Arctic (which seems to the Royal Commission to be highly desirable), that authority should be divided between seal research in the Arctic and seal research in the other regions. This split in research on the same biological taxa seems less undesirable than the present split between polar bears and seals, that is, in research into the same ecosystem. Management policy in the Arctic also will have to take account of the legal position relative to the authority of aboriginal peoples over natural resources. (See Chapter 13.)

While the Royal Commission believes that responsibility for seals in the Atlantic and Pacific Oceans should continue to belong to DFO, it believes that within DFO there should be a clear division, especially in respect of policy formulation, between fisheries and seals. If possible, a separate unit, preferably headed by a senior officer, should be formed for sealing administration.

Another consideration relates to legislation for dealing with problems of seals. At present, seals and other marine mammals fall within the scope of the *Fisheries Act* which, on strict taxonomic grounds, is not wholly appropriate. For that reason, separate legislation to cover seals and, perhaps, marine mammals in general (possibly along the lines of the United States *Marine Mammal Protection Act of 1972)* might be indicated. With increasing significance of the interactions among seals, fish and other members of the marine ecosystem, however, such a legislative separation in coverage has serious disadvantages, even in biological terms. Whatever the superficially apparent benefits of a specific seal (or marine-mammal) act might be, the Royal Commission does not believe that they would be sufficient to justify the time and trouble involved in the preparation and enactment of new legislation.

Formulation of Policies

In his presentation to the Royal Commission on behalf of the International Union for the Conservation of Nature and Natural Resources

(IUCN), R.F. Scott (1985) pointed out the value of a scientifically based plan, agreed upon by all interested parties, for the management of any exploited natural population. While such a long-term plan for Canadian sealing, had it existed, probably would not have deflected all opposition to the seal hunt, it might have mitigated the problem to a significant degree. Much of the attack on the Canadian authorities arose not so much because of poor implementation of the chosen management policy as from disagreement over the policy being implicitly pursued. To be specific, certain individuals and groups explicitly reject the idea that sealing policy should be based on the treatment of seals as solely or mainly a harvestable resource. The extent to which such views receive public support makes it essential that they be taken into account in policy formulation.

The Royal Commission, therefore, while accepting DFO's retention of responsibility for the formulation and implementation of sealing policy, believes that provision must be made for input into the policy-making process from those representing the widest possible range of interest and knowledge. Specifically, the Royal Commission considers that a permanent mechanism (probably to be incorporated under legislation) should be established to advise DFO on the management and use of the seal resources of Canada. This advisory body (council or group) should be representative of biological, economic, social and ethical concerns and of public opinion on these matters. (Consideration might be given to the inclusion, perhaps only as observers, of participants from outside Canada, such as representatives of IUCN.) It should be assisted by a technical committee to provide advice on the tactical implementation of management strategy. If, for example, it were determined that growth of the grey seal population should be curtailed, it would be the committee's obligation to advise the administration concerning the measures (the number of seals to be culled, and so forth) to be taken.

While the Royal Commission believes that establishment of such an advisory committee would be of value to the Canadian government, both in formulating a soundly based policy for the management of the seal populations and in making it apparent to the public that a wide range of opinion had been taken into account, the Royal Commission recognizes that the decision-making authority would continue to reside with the government. In addition to its ultimate responsibility, the government may take notice of, and give weight to, considerations which were seen by the advisory committee as having little or no significance. Further, it may well be that the advisory committee is unable to reach a consensus on some matters of importance, and it is unlikely that any government would regard a simple majority vote within such a group as a convincing basis for significant management decisions. The question of the likelihood of reaching consensual advice

must be an important consideration in determining the composition of the advisory committee if one is established. Any decision on this question would have to be made in the face of conflicting pressures.

The narrower the range of interests represented on the committee, the more easily will consensus be achieved but, on the other hand, the more open will the government be to criticism that it is packing the group to achieve its own purposes. The same considerations could apply in the case of a technical committee such as the one suggested above. While it might be thought that such a group would be dealing with facts established on the basis of scientific evidence, matters of judgment, in actuality, are heavily involved in the interpretation even of scientific evidence. Although all scientists probably regard themselves, personally, as viewing evidence dispassionately, there is no doubt that a sizeable proportion of those working in such fields as marine-mammal management are regarded by some among their professional colleagues as consistently leaning in their judgments toward particular approaches to management. In these circumstances, it sometimes can be almost as difficult for a scientific advisory group to reach a consensus as it is for a less technically expert body to do so – as the International Whaling Commission has learned to its cost.

The Royal Commission does not think it appropriate to put forward detailed proposals for the composition of the advisory body and its technical committee and for their terms of reference. The body certainly should include representatives of sealers, of both harvesting and processing interests in the fishing industry, of aboriginal organizations and of environmental interests, as well as of government agencies such as DFO, and the Ministry of Environment, and of others such as university staff in the fields of biology (especially quantitative ecology), economics, sociology and philosophy. Consideration might also be given to separate groups for, or some clear division within the main group between, the Arctic region and the Atlantic and Pacific regions.

International Considerations

The events of the last few years have shown that problems of seals and sealing cannot be considered as purely a Canadian matter. Seal stocks are among the largest stocks of wild animals and some of them move from national to international waters or between the territorial waters of different countries. Their welfare is thus of international interest, especially in the United States and Europe. Just as it is important that Canadian policy

take account of all points of view and not only those of sealers and fishermen, it is also desirable that the views of people outside Canada be given some consideration. The Royal Commission, therefore, considered what mechanism might be devised for that purpose.

One alternative might be some form of international commission, like the several commissions for international fishery management. The closest analogy, that of the International Whaling Commission (IWC), is not comforting. The IWC has come under heavy criticism, not all fully justified, over its failure to effectively manage the stocks of large whales in the Antarctic and elsewhere. Of more concern in the present context is the degree to which the IWC has become polarized politically between states engaged in whaling and those that have taken a strong position against whale hunting. Although the IWC has agreed that its decisions should be based on science and not politics or economic interests, the agreement merely has had the effect of pushing political in-fighting from the IWC itself into the debates of its scientific committee. Attempts to prevent this are frustrated by the great uncertainties surrounding the results of most whale studies – which, on the whole, are no greater than those that surround most seal studies. Thus agreement on, say, a precise estimate of the sustainable yield of a given stock often becomes difficult or impossible because it involves issues of judgment by scientists with conflicting views. The experience with whales suggests that the establishment of an international sealing commission, with membership open to all, would not be a helpful endeavour. On the other hand, if membership were restricted solely to countries with sealing industries, the existence of a commission would not remove the criticism that the views of the wider world were being left out of account in the formulation of Canadian sealing policy.

It seems probable that the factors that have led to a wide range of countries becoming members of IWC, and to the clash between exploitative and conservational interests within that Commission, would apply also to any new international commission for seals, especially if it were expected to make formal recommendations about the management of seal stocks. It may be noted that Canada withdrew from the IWC in 1982 as a result of general dissatisfaction with its operations and specific concern over its role in relation to the management of small cetaceans in the Canadian Arctic.

On the scientific side, the prospects for productive international collaboration are brighter. The memberships of both ICES and NAFO are broad and include many of the countries whose citizens have been most vocal over the sealing issue. As these agencies now operate, the participants in their meetings are predominantly scientists working in government-funded fish-

ery research laboratories. As such, they might be held by some environmental interests to be not altogether unprejudiced, especially in the matter of interaction with fisheries. Even if that attitude were justified, it could be dispelled by widening the participation at meetings of technical working groups and similar bodies. To some extent, criticism of this kind might be reduced by means of the procedures proposed for more extensive consultation within Canada, including the establishment of an advisory committee with extensive membership. Indeed, consideration might be given to the inclusion of participants, if only as observers, from outside Canada, for example, from agencies such as IUCN, the U.S. Marine Mammal Commission and so on. Despite the other failings of the IWC, the activities of its scientific committee have shown that scientists from universities and other non-government institutions can work effectively in intergovernmental bodies and do not necessarily have to be part of national delegations or represent formal organizations.

A proposal for an international convention for the conservation of seals in the north Atlantic was put forward by Canada in discussion with representatives of the European Community (EC) and Norway in 1982 (Canada, DFO, 1985, Appendix XXXVII). This convention, it was suggested, would

> *a) Provide a system through which internationally agreed recommendations could be made to governments under whose jurisdiction seals were harvested, with a view to ensuring coherent and rational management of the seal stocks.*
>
> *b) Ensure that the parties engage in a rational consideration of all issues involved in the harvesting of seals.*
>
> *c) Provide a focus for the exchange of scientific information, discussion of research and consideration of joint research proposals on all seal stocks in the north Atlantic Ocean.*

In 1982, Greenland was still part of the EC and, consequently, a significant proportion of the kill of harp and hooded seals was under the latter jurisdiction. From the timing of the proposal, it seems also that an additional purpose of the convention would be to defuse some of the conflict between Canada and the EC over the sealing issue.

It appears that the Government of Canada had in mind a body with membership restricted to countries having a direct interest in sealing and with terms of reference chiefly of a scientific and technical nature. As such, it would have been potentially vulnerable to the criticism (noted earlier) that it was not fully representative of international concerns over seals. This may well have been the reason that the proposal was not accepted by the EC. On the other hand, it is unlikely that a more widely based convention, similar to the IWC, would have been acceptable to Canada.

A possible reason for a new commission is that not all species of seal live throughout their lives in waters under Canadian jurisdiction. Canadian stocks of harbour, grey, ringed and bearded seals probably are restricted to Canadian coastal waters, except for limited interchange across borders with the United States and France (St-Pierre et Miquelon). Harp and hooded seals, however, migrate between Canada and Greenland and are harvested in both countries. They may spend some time in waters in the middle of the Labrador Sea beyond the 200-mile limits of the two countries, but this involves a small part of the total population for a short period of each year. Canada's international commitments in respect of these species are dealt with through membership in NAFO. Northern fur seals carry out long migrations which take them through the waters of several countries as well as into waters beyond national jurisdiction. Canada and the other countries concerned have long recognized their international obligations regarding this species. The two species of sea lion migrate between Canadian and U.S. waters. In the absence of any significant hunt for these species, however, no formal arrangement for their conservation appears to be called for.

Since 1982, little action seems to have been taken by Canada or other countries toward the foundation of a convention covering all aspects of seals and sealing. This may be attributable to a conviction that such an agency would not be useful. The Royal Commission would agree with that view.

Whitecoat and Blueback Hunt

In Chapter 12 it was concluded that, to current public opinion, the clubbing of "baby seals" (whitecoat harp seals and blueback hooded seals) is completely unacceptable. With the collapse of the main markets the economic justification of this hunt has virtually disappeared. So long as the hunt is still permitted by law, however, the possibility of a significant kill of whitecoats remains an issue that can severely disrupt discussion of less controversial matters. The Royal Commission therefore believes that the killing of

the pups of harp seals (whitecoats) and hooded seals (bluebacks) for commercial purposes should not be permitted.

The restriction to commercial hunting is deliberate, since some subsistence killing is almost certain to occur in years when the ice brings the seals inshore, close to communities in the Magdalen Islands and elsewhere with a long tradition of killing seals for their own use. Public opinion does not seem to object nearly so strongly to this form of sealing. It seems wrong in principle to make an act illegal which in practice would be difficult or impossible to prevent on an small scale, and to which there are few very serious objections. Action should be taken, nevertheless, to ensure that any non-commercial harvesting of seal pups is limited in scale and conducted humanely.

Other Commercial Sealing

While some groups object to all killing of seals, objections to the killing of older seals are much less intense and much less widely held than are those relating to the killing of seal pups. The level of objections does not seem to warrant an immediate cessation of those forms of adult sealing which are important to many local communities. While the marketing of any seal product faces problems, the problems are much less serious, and the potential for economic benefit is greater, for an adult seal hunt than for a whitecoat harvest.

With the elimination of the large-scale killing of pups, smaller catches of older seals clearly offer no threat to the stocks of harp or hooded seals. A question exists concerning the status of some local stocks of ringed seals but no threat is posed thereby to the population as a whole. For most types of sealing cruelty and suffering is not a problem. The exceptions are netting and the deliberate shooting of seals to wound them so that they can be more easily approached and killed without a high risk of loss. As considered earlier, these forms of sealing should be phased out as soon as possible. (See Chapter 20.)

With these exceptions the Royal Commission does not believe that any immediate changes are necessary in the hunting of seals other than pups. It is essential, however, that the stocks concerned be properly monitored and that the operation of any hunt be kept under review to ensure that the infliction of inadmissible pain is avoided. It is also important that the state of public opinion and public information be kept under review, and that action be taken to ensure that the public has adequate information on which to make balanced judgments about sealing policy and practices.

Population Control

The possible control of seal populations on the grounds that seals damage fisheries will almost certainly present the most difficult problems in seal management in the next few years. The background to this issue is presented in Chapter 29, where it was shown that the extent of the total impact could be very considerable, but that there is much room for doubt about the exact extent of the different effects and the ways in which these could change in response to changes in seal abundance. It was also noted that as seal stocks increase, these problems will grow. The most urgent problems concern the harp and grey seals in the Atlantic region.

Although the total impact of harp seals on Canadian fisheries in dollar terms might be similar to that of grey seals, much greater uncertainty surrounds its possible magnitude. The effect per seal is clearly much smaller, and the reduction in total impact by a given amount would almost certainly involve killing a much larger number of seals. To achieve any significant control of harp seal numbers would involve killing several tens of thousands of animals, and it seems inevitable that a cull of this magnitude, coming so soon after the public outcry against the commercial harvest of harp seals, would involve a fresh public outcry on a comparable scale. Strong arguments against a cull from environmental and animal-welfare groups are particularly likely to occur in view of the substantial uncertainties that surround current estimates of the extent of the impact of harp seals on fisheries.

These doubts, especially those concerning the effects of competition for capelin and other fish, could be substantially reduced by increased research on these topics. In a few years it should be possible to have much better estimates of the extent of the impact. By that time also, the effects on the public of the recent anti-sealing campaign may largely have disappeared, and it should be possible to make a decision on whether or not to cull in a much less polemical atmosphere. The Royal Commission therefore believes that there should not be any cull of harp seals at the present time, but that the situation should be carefully reviewed in the light of new research, in two or three years' time. The Royal Commission also believes that serious consideration should be given to the advantages of employing ex-sealers in any future cull. Especially if these were to come from the communities that had been most gravely affected by the collapse of the sealskin market, the net economic and social benefits of a cull could be significantly increased.

The factors affecting a possible grey seal cull are more evenly balanced. The impact on the fisheries of an individual seal is, on the average,

clearly larger and is estimated with greater certainty, even though it is far from clear what the marginal effect of a small or moderate reduction of seal numbers would be on the damage caused to fisheries by seal-transmitted parasites. The economic benefit to Canadian fisheries would almost certainly exceed by several times the cost of a cull. It is unlikely that the outstanding doubts would be substantially reduced by research over the next two or three years, although such research would increase reliability to some extent and should not be neglected. The grey seal stocks are also increasing, certainly at Sable Island and almost certainly in Canadian waters as a whole, and the effect of competition, at least, will increase more or less in proportion. Any delay in deciding on a cull will compound the problem and even greater numbers would need to be killed if a cull were to be decided upon later. The case for postponing a decision is therefore much less convincing for grey seals than it is for harp seals.

On the negative side, it is possible that there would be wide public opposition to any cull of seals. Although culling of grey seals has been carried out regularly in the past without becoming the focus of much public attention, now that the commercial hunt of whitecoats is essentially finished, it is very probable that some, though not all, of the anti-sealing groups will focus their attention on the remaining instances of the killing of seals. The question of possible public attitudes is made more significant by the fact that if the cull is to be effective and carried out at reasonable cost, some of the seals would probably have to be killed on Sable Island. This place has the status of at least an unofficial nature reserve, and the killing of seals there would be likely to provoke more opposition than recent culls in the Gulf of St. Lawrence.

To reach a balance between the essentially economic factors indicating the desirability of a cull and the public reaction against a cull is not easy. This has to be a political decision in which good information on the nature and extent of potential opposition must be a key factor. The Royal Commission had little relevant information on this issue available to it. Indications from the poll conducted by Canadian Gallup Poll Limited for the Royal Commission (Chapter 11) suggest that the shooting of older seals might meet significantly less opposition than the clubbing of pups, but this evidence is not conclusive.

The best indication of public reaction should come after the publication of the Royal Commission's Report which, in addition to bringing the problem fully to the public's attention, also contains reasonably quantitative, though still definitely approximate, estimates of the extent of the economic impact of seals on fisheries. On that basis, the decision whether or not

to cull grey seals should be made soon. To ensure that public viewpoints on culling are taken into account, the decision should be made with the assistance of the representative advisory group proposed above.

If a decision is made in principle that grey seals or any other species of seals should be killed in order to reduce the impact on fisheries, further decisions need to be made on the number of seals that should be killed, the agents responsible and the manner of financing the operation. The determination of the number of seals to be killed and the sites of the kill are technical matters that should readily be settled in the light of the knowledge of the dynamics of the population in question. Account should also be taken of the need to minimize the risk of suffering, by shooting seals on land rather than on the water, for example, and to avoid undue costs.

Discussions in Chapter 29 point clearly to the desirability of any cull being carried out under the direct control of government so as to avoid cruelty, and to ensure that only the desired numbers are killed and that full biological information is collected. Bounty schemes as incentives for fishermen to kill seals are undesirable. Where fishermen are allowed to kill seals in their own immediate interests, near traps or other fixed gear, for instance, a small sum to cover the additional expenses involved might be paid in order to ensure the provision of biological information.

If the costs of a cull are small, they can be borne by the government as part of its general support for the fishing industry without raising significant questions. If costs are not small, then attention needs to be given to the question of who should pay for a cull. It might be argued that the impacts of seals are like the losses incurred in a normal period of bad weather, and should be borne by the fishing industry itself. It might also be considered that government-financed culls – and even more, government-financed bounty schemes – are concealed forms of subsidy.

If, indeed, there are to be significant financial benefits from controlling grey seals, it is possible that the industry itself might wish to arrange for the financing of culling costs. If it did so, it would provide a clear indication, in response to those who might doubt the evidence of the extent of the impact of seals on fisheries, that those directly concerned had no doubts and were prepared to financially back their views. This demonstration, in turn, would make public acceptance of the desirability of carrying out a cull more likely.

The possibility exists that, if there were strong public opposition, the government might not agree to carry out a cull, even though it would be

financed by the industry. In such a case, some form of compensation might possibly be contemplated. This should relate not to the total extent of damage from seals but to the net effect (reduction of damage less cost of culling) projected for a cull.

Conclusions

Since 1966, when mechanisms were established for effective international management of seal stocks, and especially since 1977, when Canada established jurisdiction over sealing and fisheries to a 200-mile limit, the management authorities have been successful in halting the decline in the abundance of harp and hooded seals. Effective measures have also been taken to reduce the amount of unnecessary cruelty involved. Canadian management objectives and practice have been consistent with sound conservation principles as set out, for example, in the World Conservation Strategy.

The Canadian management authorities have been fully responsive to the technical advice given concerning the status of the stocks and the use of different kinds of killing methods. They have been less responsive to those who have questioned the basic objectives of policy, and who have wished less emphasis to be placed on the use of seals as an economic resource.

The costs incurred by the Canadian government in relation to sealing have represented a significant, but in view of its nature, not an unduly high proportion of the total value of the hunt. Costs have been increased by the need to respond to the anti-sealing movement. Not all costs could be eliminated even if there were no sealing. Taking account of the growing awareness of the interaction between seals and commercial fisheries, and the great uncertainties surrounding many aspects of this interaction, the amount spent on seal research may need to be increased.

Many uncertainties surround all aspects of the impact of seals on fisheries. The present impact caused by the competition between seals and fishermen for the same stocks of fish is particularly uncertain, as is the extent to which the impact would be changed, in the case of damage due to transmission of parasites, by an increase or decrease in the number of seals. Resolution or reduction of these uncertainties is critical to the decision whether or not to institute a cull for any species of seal, and will require intensified research. Monitoring of the seal stocks and further research into their population dynamics also is needed.

Responsibility for seals and sealing is at present entrusted to DFO. This has meant that sealing policy is weighted towards, or at least is believed to be weighted towards, the treatment of seals primarily as a resource to be harvested for economic return or as animals to be controlled in the interests of fishermen. Those with different views about seals feel that their concerns are not adequately represented in the formulation of Canadian policy. The Royal Commission concludes that DFO, however, is the appropriate agency for dealing with most aspects of seal management, including research, the collection of statistics and the implementation of regulations.

In the Arctic, management policy for seals must be co-ordinated with the management of the predators on seals (bears and foxes). It will also have to take account of the legal position of aboriginal peoples with regard to control of the resources involved.

The formulation of a long-term seal-management plan or some similar expression of basic policy objectives, in which there would be inputs from a broad spectrum of interests in addition to DFO, could remove much of the present bitterness over sealing. This acrimony has arisen less from differences over technical matters than from fundamental differences in points of view about seals and sealing. Once a basic policy has been agreed upon by a group which includes environmental interests, DFO should have much fewer problems in implementing that policy.

The immediate need for such a policy is greatest in relation to the interactions between seal stocks and fisheries. Although not known precisely, the amount of loss caused, in one way or another, to the fishing industry, especially on the Atlantic coast, is already high and is likely to increase because, under current harvest rates, both harp and grey seals, which account for the greater part of the damage, are increasing in numbers.

Recommendations

1. The Department of Fisheries and Oceans, with the assistance of a representative advisory group, should explicitly establish for each seal stock both priorities for management and use that reflect social and economic values and management plans based on these priorities.

2. Management plans should be based on information on seal numbers, on seal impacts on fisheries and on public attitudes toward the killing of seals. They should include proposals for target levels of populations in the medium term, and for the number of seals, if any, that may be

killed in population control programs, subsistence hunting and commercial sealing.

3. Federal responsibility for seals in the Arctic should be closely co-ordinated with responsibility for the rest of the arctic ecosystem. Policy formulation should be a co-ordinated process involving aboriginal peoples, the Government of Canada and the Government of the Northwest Territories.

4. The government should consider transferring responsibility for seals on the Atlantic and Pacific coasts to a section of DFO, separate from those directly concerned with fisheries. The responsibilities of this section should include the protection of seals, management of any utilization and the interaction with fisheries.

5. Seal-management policies should be supported by an active, well-coordinated research program addressed to all the relevant issues. The financial and staff resources given to this program should be substantially greater than those given to seal research in recent years.

6. Non-commercial hunting of pups of harp seals (whitecoats) and hooded seals (bluebacks), to the extent that it occurs at all, should be carefully regulated and strictly limited.

7. Observers should be permitted to view any operation in which seals are killed, subject to such legal constraints as are necessary to protect personal rights and property.

Appendix

Appendix 30.1 Changes to Seal Protection Regulations[a]

June 1959 SOR/59-191[b]	• Seal Protection Regulations (P.C. 1959-724) replaced Seal Protection Regulations made by Order in Council P.C. 5293-18 October 1949. • Defined "resident" in terms of "defined area." • Described "defined area" as waters north of 60° N and all of Ungava Bay, Hudson Bay and James Bay.

Appendix 30.1 Changes to Seal Protection Regulations[a] (continued)

	• Prohibited killing seals in the defined area except by residents for food and by others for scientific purposes.
	• Provided for sport hunt in certain areas north of 60° N under licence.
	• Limited sale and disposal of seal meat in defined area.
February 1961 SOR/61-60	• Set out "Front Area" and "Gulf Area."
	• Established closed seasons for Front Area and Gulf Area.
	• Required licences for sealing from vessels.
April 1961 SOR/61-160	• Closed seasons in Front Area and Gulf Area lengthened.
February 1962 SOR/62-59	• Prohibited use of aircraft for spotting, except under licence.
	• Prohibited killing from aircraft.
May 1962 SOR/62-171	• Established Cape Dorset and Whale Cove Regions.
	• Made minor changes in definitions.
	• Applied controls to sport hunting in Cape Dorset Region and Whale Cove Region.
	• Set sport quotas of 40 in each region.
	• Set daily sport bag limit of 3, only 1 of which might be a bearded seal.
	• Provided for the use of Inuit guides.
	• Prohibited retention of over 25 lb of meat by sport hunters, with excess to go to the Inuit.
January 1963 SOR/63-16	• Established sport hunting quota for Frobisher Bay at 50 seals.

Appendix 30.1 Changes to Seal Protection Regulations[a] (continued)

	• Permitted grey seals and harbour seals to be killed any time without a licence in areas where a bounty was offered.
April 1963 SOR/63-135	• Defined "Frobisher Bay Region."
	• Changed regional sport hunting quotas to 60 seals each in Cape Dorset, Whale Cove and Frobisher Bay Regions.
	• Required use of aboriginal guides and their boats.
	• Changed the seasons in Gulf and Front Areas.
March 1964 SOR/64-99	• Seal Protection Regulations (P.C. 1959-724) of June 1954 revoked and replaced by Seal Protection Regulations (SOR/64-99) of March 1964.
	• Prohibited seal hunting in the "defined area" except by residents for food or when authorized by the Minister for scientific purposes.
	• Instituted sport hunting provisions for Cape Dorset, Whale Cove, and Frobisher Bay Regions, with sport quotas established at 40, 60, 60, respectively, and daily limits of 3, only 1 of which might be a bearded seal.
	• Required that aboriginal guides and their boats be used by sport hunters; prevented retention of more than 25 lb of seal meat by sport hunters.
	• Prohibited sealing from vessels over 40 ft in length in the Gulf and Front Areas without licence.
	• Prohibited use of aircraft for spotting except with licence.
	• Prohibited the killing of seals from an aircraft.
	• Defined seasons in the Gulf and Front Areas.
	• Permitted killing of grey and harbour seals in bounty areas without a licence.

Appendix 30.1 Changes to Seal Protection Regulations[a] (continued)

	• Set licence fees for vessels 40 ft and over, 65 ft and over, 100 ft and over, OAL.[c]
November 1964 SOR/64-443	• Seal Protection Regulations (SOR/64-99) revoked and replaced by Seal Protection Regulations (P.C. 1964-1963).
	• Retained provisions as per SOR/64-99 (preceding regulations).
	• Divided Gulf Area into Districts.
	• Required sealing licences for all vessels over 30 ft in overall length.
	• Closed District 2, Gulf Area to the hunting of hooded seals.
	• Set a quota for whitecoats in District 2, Gulf Area.
	• Prohibited use of aircraft in seal hunt except in District 2, Gulf Area; permitted use for spotting only, in the remainder of the Gulf Area and the Front Area; licences required in all cases; killing of seals from aircraft not permitted.
	• Closed seasons for sealing from aircraft or vessels in Gulf Area and Front Area.
	• Provisions allowing Minister to vary Gulf Area closed season.
	• Required sealer's licence.
	• Prohibited sealing with longlines.
	• Set minimum weight and length for clubs.
	• Prohibited skinning before death.
	• Prohibited killing of adult seals in breeding and whelping patches.
	• Required all sealskins to be removed daily from the ice to the base of operations.
	• Permitted killing of grey and harbour seals without licence in bounty areas.

Appendix 30.1 Changes to Seal Protection Regulations[a] (continued)

	• Established licence fees.
March 1965 SOR/65-100	• Allowed use of aircraft in special circumstances in District 1, Gulf Area and the Front Area for 1965 only.
June 1965 SOR/65-238	• Defined Coronation Gulf and Tuktoyaktuk Regions.
	• Reduced sport-sealing quotas to 2 seals annually.
	• Prohibited sport sealing of bearded seals.
February 1966 SOR/66-101	• Redefined Front and Gulf Areas.
	• Redefined Districts 2 and 3, Gulf Area.
	• Required that vessels over 30 ft in overall length be licensed; licence subject to terms and conditions prescribed by Minister.
	• Prohibited killing of hooded seals in Gulf Area.
	• Established quota for seals less than 1 year of age in District 2, Gulf Area.
	• Provided for cessation of hunt in District 2, Gulf Area by Ministerial order.
	• Restricted aircraft-sealing licences to Canadian aircraft, subject to terms and conditions.
	• Required all sealers in Gulf and Front Areas to have a sealer's licence.
	• Restricted killing weapons to (a) a gaff (defined) (b) a club (defined) (c) a rifle (defined)
	• Except in District 1, Gulf Area and a portion of the Front Area, where net fishing by local residents permitted.

Appendix 30.1 Changes to Seal Protection Regulations[a] (continued)

	• Prohibited hunting of adult seals in whelping or breeding patches.
	• Required that pelts be removed from ice within 24 hours.
	• Prohibited the removal of live seals except under permit.
March 1966 SOR/66-115	• Authorized the Minister, for conservation purposes, to stop hunting in the Gulf by sealers operating from vessels less than 30 ft OAL or from shore.
May 1966 SOR/66-235	• Seal Protection Regulations (P.C. 1964-1663) of 29 October 1964 revoked and replaced by Seal Protection Regulations (SOR/66-235, P.C. 1966- 904).
	• Retained provisions per P.C. 1964-1663 (preceding regulations).
	• Defined "person of mixed blood."
	• Prohibited taking seals by longline.
January 1967 SOR/67-52	• Added definition of "sealing."
	• Described seals by common and scientific names.
	• Exempted land-based aircraft searching for seals from the requirement to have a sealing licence.
	• Required all sealers in the Gulf and Front Areas to be licensed and to wear specific visible means of identification.
	• Set out criteria for acceptable clubs, rifles and shotguns.
	• Required use of clubs only for striking live seals and that seals be struck only on the forehead.
	• Prohibited hooking, skinning, bleeding or cutting of any seal until the seal is without doubt dead.
	• Required removal of seal pelts killed the previous day before killing could be continued.

Appendix 30.1 Changes to Seal Protection Regulations[a] (continued)

	• Made masters of ships and pilots of aircraft responsible for the behaviour of their crew or passengers.
	• Restricted hunting hours in the Gulf Area.
	• Provided for immediate suspension of a licence by a fishery officer for a period not exceeding 30 days.
March 1968 SOR/68-78	• Changed Front and Gulf seasons.
February 1969 SOR/69-79	• Changed Front and Gulf seasons.
March 1970 SOR/70-108	• Redefined Gulf Area and Front Area.
	• Defined "whitecoat."
	• Prohibited killing of whitecoats in Districts 2 and 3 of the Gulf Area.
	• Prohibited use of aircraft in sealing except while searching for seals.
	• Required searching aircraft to be licensed.
	• Restricted aircraft eligible for licensing to those registered under Part II of the Air Regulations made pursuant to the *Aeronautics Act*.
	• Provided for prescribing of terms and conditions in an aircraft-sealing licence.
	• Prohibited landing of aircraft less than 1/2 nm[d] from any seal herds in the Gulf or Front Areas.
	• Defined seasons for all sealers in the Front and Gulf Areas, with an exception for residents of District 1 of the Gulf Area operating from shore or from vessels of less than 30 ft OAL.
	• Removed requirement that a pilot be responsible for the hunting behaviour of his crew.

Appendix 30.1 Changes to Seal Protection Regulations[a] (continued)

March 1971 SOR/71-127	• Defined "registered net tonnage." • Removed division of Gulf Area into Regions. • Stopped issue of vessel-sealing licences to vessels of over 65 ft OAL unless those vessels were licensed in 1969 or 1970. • Set quotas for harp seals of 50,000 in each of Gulf Area and Front Area for vessels over 65 ft. • Revised sections pertaining to seasons in Gulf Area and Front Area. • Restricted off-season taking of seals from shore or small boats to local residents. • Restricted netting of seals to local residents. • Amended licence fees.
August 1971 SOR/71-397	• Established closed season for Murray Harbour, P.E.I.
December 1971 SOR/71-648	• Revised closed season for Murray Harbour.
March 1972 SOR/72-72	• Revised eligibility criteria for licensing vessels over 65 ft OAL. • Revised harp seal quota for Front Area vessels over 65 ft OAL. • Prohibited harp seal hunting in Gulf Area from vessels over 65 ft OAL. • Set combined harp seal quota for landsmen in Gulf and Front Area.
June 1972 SOR/72-186	• Provided some relaxation of seal sport-hunting provisions for residents of defined areas.
March 1973 SOR/73-159	• Revised seasons for harp seals in Gulf and Front Areas and for hooded seals at Front.

Appendix 30.1 Changes to Seal Protection Regulations[a] (continued)

April 1974 SOR/74-216	• Redefined "resident." • Prohibited landing of aircraft within 1/2 nm of a seal.
March 1976 SOR/76-172	• Defined "hakapik" and "sealing crew." • Revised quota for harp and hooded seals hunted at the Front from vessels over 65 ft OAL. • Prohibited landing aircraft within 1/2 nm of a seal except under permit. • Prohibited overflying seals at less than 2000 ft altitude except under permit. • Adjusted hunting seasons for harp and hooded seals in Gulf and Front Areas. • Required hunters to hold either sealer's or assistant sealer's licence. • Established criteria for sealer's and assistant sealer's licence (i.e., sealers: 18 years of age or over, 2 or more years experience sealing and being a sealing group leader; assistant sealers: 15 years of age or over). • Limited hunting activity of inexperienced sealers. • Permitted use of hakapik in Front Area. • Established closed season for grey seals. • Prohibited tagging or marking of live seals except under permit. • Limited hunt to specific hours during the day. • Amended licence fees.
February 1977 SOR/77-181	• Defined "Regional Director." • Redefined "hakapik."

Appendix 30.1 Changes to Seal Protection Regulations[a] (continued)

	• Adjusted eligibility criteria for sealing-vessel licences.
	• Revised quotas and seasons.
	• Permitted variation of seasons or quotas by a Regional Director General.
	• Provided for broadcast or publication of variation orders.
	• Permitted sealing from vessels over 65 ft OAL in Gulf with Ministerial permission.
	• Set out adult sealskin quotas for large vessels as percentages of catch on board (5% harps over 1 year; 10% female hoods).
	• Required persons operating from shore or in small vessels to take seals only off that part of province where they reside.
	• Ordered that hooded seals be struck with a hakapik after being shot.
	• Revised some hunting hours.
October 1977 SOR/77-828	• Revised provision for closed season in Murray Harbour and added a closed season for Gaspé.
C.R.C. 1978 c. 833	• Consolidated Regulations of Canada, Chapter 833.
February 1978 SOR/78-167	• Defined Lake Melville Area.
	• Defined "landsman."
	• Permitted residents of Labrador to take seals at Front at any time.
	• Added prohibition against persons without permits coming within 1/2 nm of any area where sealing is taking place.
	• Detailed application requirements for a permit to visit the hunt.
	• Restricted harvesting of ringed seals in Lake Melville Area to residents.

Appendix 30.1 Changes to Seal Protection Regulations[a] (continued)

	• Required that Lake Melville hunters hold sealer's licences.
	• Required that a club or hakapik be on board a sealing vessel.
	• Established various means by which ringed seals in Lake Melville might be taken.
	• Established criteria necessary to declare a seal dead.
	• Imposed a duty on vessel masters to ensure their crews complied with the Regulations.
	• Revised hunting hours.
	• Added ringed seals to Schedule II.
	• Revised Schedule III relating to quotas and seasons.
March 1978 SOR/78-237	• Revised schedule to read "Canadian" rather than "Gulf" based vessels over 65 ft OAL.
March 1979 SOR/79-213	• Modified Front Area and Gulf Area.
	• Redefined "sealing."
	• Revised provisions on licensing large vessels.
	• Provided for possibility of issuing new vessel licences.
	• Limited validity period of licences.
	• Further limited catch of female hooded seals.
	• Permitted use of hakapik in Gulf by sealers from large vessels.
	• Required exsanguination of a dead seal.
	• Provided a closed season in St. Lawrence and Saguenay Rivers.
	• Modified Schedule III dealing with quotas and seasons.

Appendix 30.1 Changes to Seal Protection Regulations[a] (continued)

September 1979 SOR/79-676	• Corrected inconsistencies between French and English versions.
February 1980 SOR/80-115	• Redefined Lake Melville Area. • Set out eligibility criteria for licensing sealing vessels over 65 ft OAL. • Restricted daily kill of adult female hooded seals by sealers operating from a vessel over 65 ft to 5% of total number of hooded seals taken by sealers from that vessel. • Required that the hood remain attached to all adult male hooded seals until taken on board a vessel. • Required that all seals killed by means of a club or hakapik be struck on head three times or until skull is crushed. • Prohibited a "sealing group" from stockpiling more than 10 seals that have not been pelted.
December 1980 SOR/81-18	• Altered some licence fees. • Amended some seasons.
February 1982 SOR/82-269	• Redefined Front Area and Gulf Area. • Required all vessels 35 ft or more OAL to be licensed to engage in sealing. • Revised quotas and closing times for 1982 sealing and revised procedure for varying quotas and closing times. • Increased percentage of harp seals 1 year or older that a vessel over 65 ft may have on board (from 5% to 6%). • Prohibited landsmen operating from vessels 35 ft or more OAL from taking whitecoats in Front Area and the northern portion of Gulf Area.[e]

Appendix 30.1 Changes to Seal Protection Regulations[a] (continued)

	• Set out revised licence criteria for sealer's licence and assistant sealer's licence.
	• Redefined maximum length and width for club used to kill seals.
	• Restricted taking of grey seals under bounty to licensed sealers.
July 1983 SOR/83-588	• Removed reference to Minister of Province of Quebec in the licensing provisions.
December 1983 SOR/84-64	• Revised definition of "Regional Director General."
	• Revoked duplicative section.
February 1984 SOR/84-201	• Clarified that a person, when clubbing a seal, must crush the skull before proceeding to skinning stage.

Source: Canada, DFO (1985).

a. Seal Protection Regulations were first made by Order in Council P.C.5293-18 October 1949. These regulations which, in their present form, apply to bearded, grey, harbour, harp, hooded and ringed seals, define the areas, times and methods by which seals may be killed; and prescribe certain other conditions, including those related to sport hunting, the use of meat, licence requirements, the use of helicopters or other aircraft, and observers approaching a seal or an area where the hunt is being carried out. Requirements relating to licence fees, quotas and closed times are included as schedules to these regulations.
It is important to note that quotas and closed times may be changed by "variation order" so that quotas listed in the regulations do not necessarily reflect those actually in effect. For example, while the 1983 regulations list the quota for hooded seals as 15,000, the quota was actually 12,000. In 1984 and 1985, the quota for hooded seals was set at 2,340; however, because anticipated harvest levels were substantially lower than this number, variation orders were not issued.

b. SOR = Statutory Orders and Regulations.

c. OAL = overall length.

d. nm = nautical mile

e. This was the result of an industry decision and was made in exchange for an allocation of hooded seals.

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Scott, T.H. 1985. Brief to the Royal Commission on Seals and the Sealing Industry in Canada. On behalf of World Society for the Protection of Animals, London.

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Administrative Appendix

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Administrative Appendix

1. Statement of Policy and Procedure

Adopted at the first meeting of the Royal Commission, 24–26 September 1984.

Introduction

A Commission of Inquiry has been constituted under Part I of the *Inquiries Act*, R.S.C., 1970, C.I-13 by Order in Council P.C. 1984-2242 dated 22 June 1984 to conduct a full inquiry as more particularly set out in the terms of Reference into seal resource management and the seal industry in Canada.

The Commission has been directed to submit a preliminary report to the Governor General in Council not later than 31 December 1984, and its final report is to be submitted by 30 September 1985.

Commissioners

The seven Commissionners who have been appointed are:

The Hon. Mr. Justice Albert H. Malouf
Court of Appeal
Montreal, Canada
Chairman

Dr. Kenneth Radway Allen
Fisheries biologist
Cronulla, N.S.W., Australia

Dr. Patrick Geistdoerfer
Biological oceanographer
Paris, France

Prof. Robert Ian McAllister
Economist
Halifax, N.S., Canada

Mr. Russel Lawrence Barsh
Attorney - indigenous rights
Seattle, Wash., U.S.A.

Dr. John A. Gulland
Fisheries biologist
Cambridge, England

Dr. Wilfred Templeman
Marine biologist
St. John's, Nfld., Canada

Terms of Reference

The Commission's mandate is to investigate and make recommendations on all aspects of seal resource management and sealing in Canada, and especially on the economic viability of the seal industry and, without limiting the generality of the foregoing, the Commission shall inquire into and report on:

(a) the social and cultural impact and economic benefits and costs, including regulatory costs, of sealing in Canada;

(b) the ethical considerations relevant to the harvesting of seals;

(c) the status of Canadian seal stocks and measures currently in force in Canada to conserve, manage, protect and regulate the harvesting of seals, including the adequacy of such measures;

(d) the interactions between seals and commercially exploited fish populations that may affect food supplies or contribute to parasite transmission;

(e) the interaction between seal populations and commercial fisheries, including, *inter alia*, competition between seals and fishermen for fish stocks; interference in fishing activity by seals, including damage to fishing gear and catches; and the effects and related economic costs on the quality of fish catches caused by transmission of parasites by seals;

(f) the principles necessary to manage seal stocks for conservation purposes, including appropriate cull levels, so as to ensure the continuing abundance and health of seal stocks and to minimize adverse interactions between seals and Canadian fishing resources and operations;

(g) the methods for harvesting seals commercially and their suitability;

(h) the domestic and international opportunities for and constraints on the processing and marketing of Canadian seal products;

(i) the availability of alternative sources of income and opportunities for adjustment for individuals and communities currently dependent on the seal harvest;

(j) the concerns of individuals and groups with a direct, indirect or declared interest in sealing in Canada, including an assessment of such interests;

(k) the public awareness and attitudes in Canada and abroad on sealing policies and activities in Canada and the extent to which such attitudes could constrain future revitalization of commercial sealing, or adversely affect other commercial interests and activities, and recommend approaches for removing those constraints;

(l) the international comparisons, as appropriate, for the preceding elements, and

(m) the possible new international initiatives for managing Canada's seal resources, for harvesting seals and for related activities.

Office

Effective 12 November 1984, the office of the Commission shall be at:

Palais de Justice
Suite 9.80
1 Notre-Dame Street East
Montreal, Quebec
H2Y 1B6

Rules of Practice and Procedure

In order to fulfil its mandate, the Commission deems it appropriate to adopt certain rules of practice and procedure. The Commission therefore decrees the following rules:

Public Hearings

1. Hearings of the Commission will be held at such times and places as the Chairman shall decide.

2. Notice of public hearings shall be published in advance in such daily newspapers or other periodicals as are likely to convey the notice to interested members of the public.

3. Except with the consent of the Chairman, photographs, films, cable distribution, television, video tapes and all forms of recording shall be prohibited at Commission hearings, subject to Rule 13.

4. When the Chairman considers that disclosure of testimony is likely to be detrimental to the interests of justice; or to cause unwarranted prejudice to the reputation of a witness or of another person, the dissemination of such testimony may be prohibited according to the terms and conditions and for the period determined by the Chairman.

Private Hearing

5. The Commission may hold private hearings when the Chairman considers them necessary. Only those persons authorized by the Chairman will be permitted to be present at such hearings.

Administration of Proof and Hearing

6. The Chairman may designate one or more members of the Commission to gather such information as he may deem necessary to fulfil the mandate of the Commission.

7. Every exhibit or document produced shall be identified by a number which shall be used throughout the inquiry.

8. A witness who testifies at a hearing may be required to testify under oath or by affirmation.

9.1 During hearings before the Commission, persons may submit evidence and facts to the Commission on any matter within its terms of reference by oral testimony, or in such other manner as the Chairman shall determine.

9.2 The Commission may at any time it deems appropriate ask such questions as it considers useful of witnesses appearing before the Commission.

10.1 Any person, corporate body, association, organization, group of persons, union or public body (hereinafter referred to as "person")

wishing to be heard by the Commission may request the Chairman's authorization to be heard or to have other persons heard.

Such requests must be submitted in writing to the Commission and must indicate the general nature of the presentation, a list of supporting material, if any, the reasons for which the Chairman should grant the authorization, the surname(s), given name(s) and address(es) of the person(s) to be heard, and an estimate of the time required to hear the presentation.

10.2 The Chairman reserves the right to deal with the information so offered in such manner as he deems advisable, consistent with the terms of the Order in Council creating the Commission.

10.3 The Chairman may accede to this request in whole or in part, according to the terms and conditions he sets, or reject it.

10.4 When such a request is granted, the witness shall be invited to appear.

10.5 The Chairman may, in his discretion, limit the amount of time allowed to any one person for hearing a presentation.

11. The Commission may adjourn hearings at such a time and date as it considers appropriate.

12.1 Any person may testify before the Commission in French or in English.

The Commission shall, however, provide the services of an interpreter at its own expense for any person whose knowledge of French or English is insufficient for the purposes of his testimony.

12.2 Any person who wishes to avail himself of the services of an interpreter must notify the Executive Director or the clerk of the Commission a reasonable time before the date set for his hearing, indicating the language in which he wishes to testify.

12.3 Only interpreters accredited to the Commission may act at hearings.

13. During the hearings, the Commission shall have the witnesses' testimony recorded by stenography or by any other means it deems appropriate.

Submission of Written Briefs

14.1 Any person, corporate body, association, organization, group of persons, union or public body (hereinafter referred to as "person") wishing to submit a written brief to the Commission may do so by following the procedure hereinafter described.

14.2 The briefs may deal with any matter within the terms of reference of the Commission. The briefs should be as concise and succinct as possible and may be accompanied by supporting material. Each brief should be signed and should indicate the surname(s), given name(s) and address(es) of the persons responsible for the preparation of the said brief.

14.3 Whenever possible the text of each brief should be presented in typewritten double-spaced form, on one side of paper measuring 21.5cm X 28cm (8 1/2" X 11").

14.4 Ten copies of each brief should be submitted to the Commission. If it is not possible to submit such number of copies for any reason whatsoever, the Commission shall undertake to produce its own copies at its own expense.

14.5 The briefs may be submitted to the Commission on a confidential basis. However, the Chairman reserves the right to deal with the information offered in each brief in such a manner as he deems advisable, consistent with the terms of the Order in Council creating the Commission.

14.6 The persons submitting briefs to the Commission may also request to be heard by the Commission. The Chairman may accede to this request in whole or in part, according to the terms and conditions he sets, or he may reject it.

Miscellaneous Provisions

15.1 Records of the Commission shall be maintained at its office until such time that the final report of the Commission is submitted to the Governor General in Council.

15.2 Subject to Rules 4 and 16, any person who wishes to take cognizance of exhibits or documents produced or depositions obtained before the

Commission must obtain prior authorization from the Chairman. The Chairman may specify the terms and conditions under which such authorization is granted.

15.3 Any person so authorized must present himself at the Commission's office during office hours on juridicial days in order to consult the file in the presence of the Executive Director of the Commission or his representative.

16. A witness may at any time take cognizance of his deposition and of the exhibits he has produced. No other person may take cognizance of the depositions obtained and the exhibits produced without the authorization of, and according to the conditions set by, the Chairman.

17. A witness may be compelled to appear and testify before the Commission by summons and must attend the hearing at the place, time and date indicated in the summons, failing which he shall be subject to such penalty as is provided by law.

18. Any person summoned to testify before the Commission in public or private hearings shall be entitled to a reasonable travel allowance, on presentation of supporting documents approved by the Executive Director of the Commission and at a rate fixed by law, for each day on which he presents himself before the Commission, whether he testifies or not.

19. A person required by summons to produce a document or thing at a hearing of the Commission shall produce the document or thing at the place, time and date indicated in the summons, failing which he shall be subject to such penalty as is provided by law.

20. The Commission may engage the services of such consultants and staff as are required to conduct research, prepare reports, and make presentations to the Commission.

21. Anything which interferes with the decorum and good order of the hearings shall be prohibited.

22. These rules are intended to facilitate the Commission's work and must be so interpreted.

Admissibility of Photographs, Films, Videos, and Other Similar Evidence (hereinafter called photographs)

Adopted at a meeting of the Royal Commission, 22 January 1985.

23. Admissibility of photographs depends on:

a) Accuracy in truly representing the facts.

b) Fairness and absence of any intention to mislead.

c) Verification on oath by a person capable of doing so. It is not imperative that photographs be verified through the sworn evidence of the person who was responsible for taking them; other persons familiar with the event portrayed in the photographs can be permitted to identify such pictures.

The procedure will be as follows:

23.1 The person wishing to submit photographs as evidence before the Commission must forward to the Commission in writing all the pertinent details concerning such evidence including the date, time and place where the photographs were taken, the equipment used, the name of the photographer and, if applicable, the names of the director and producer of same.

23.2 The person submitting this evidence must advise the Commission whether any or all of the persons mentioned in paragraph (1) herein who are responsible for the creation and the production of the said evidence are available for examination by the Commission. Access to these individuals must be given to the Commission in order to allow it to investigate the authenticity of the said evidence. Furthermore, the person responsible for submitting this evidence to the Commission must agree to allow the Commission to analyse the evidence through the use of technical experts if necessary.

23.3 The evidence submitted to the Commission will be viewed by representatives of the Commission, and the Chairman will then advise the person wishing to submit the evidence of the conditions under which the evidence will be accepted. The Chairman may, however, refuse to accept such evidence.

23.4 The Commission, as stipulated in the "Statement of Policy and Procedure", reserves the right to deal with the evidence so offered in such a manner as the Chairman deems it advisable, consistent with the terms of the Order in Council creating the Commission.

2. Groups and Individuals Submitting Briefs to the Royal Commission

A. Garrigus Pentecostal Collegiate (Grade X class)

Abadie-Maumert, F.A.

Animal Defence League of Canada

Arche II/Ark II

Arctic Cooperatives Limited

Association des biologistes du Québec

Association des chasseurs de phoque
des Îles-de-la-Madeleine (A. Miousse)

Atlantic Marine Wildlife Tours Ltd. (J.E. Lewis)

Attagoyuk School (E. Kilabuk, C. Aningmiuq)

Baffin Divisional Board of Education (J. Mike)

Baffin Region Hunters and Trappers
Committee (S. Atagootak)

Baffin Region Inuit Association (Keyootak, P.)

Barry, Hon. L., Leader of the Opposition,
Province of Newfoundland and Labrador

Boxer, Hon. B., House of Representatives,
Congress of the United States

Brenner, J.

Canadian Federation of Humane Societies

Canadian Nature Federation (R. Fox)

Canadian Sealers Association

Canadian Society for the Prevention of Cruelty to Animals

Canadian Veterinary Medical Association

Canadian Wildlife Federation

Canadians for the Abolition of the Seal Hunt (T. Harrison)

Carino Company Limited (B. Nygaard, C. Rieber)

Chabot, J.

Chambre de commerce des Îles-de-la-Madeleine

Clarke, B.

Commission de développement des pêches des Îles-de-la-Madeleine

Committee on Seals and Sealing (T.I. Hughes)

Cournoyea, Hon. N. J., Minister of Renewable Resources,
Government of the Northwest Territories

Curley, Hon. T., Minister of Economic Development and Tourism,
Government of the Northwest Territories

Currey, J.E.

Department of Economic Development and Tourism
(Baffin Region) NWT

Department of Fisheries and Oceans, Canada

Department of Indian Affairs and Northern Development, Canada

Dupras, G.R.

Eastern Fishermen's Federation

Emond, D.P.

Eyre, S.M.

Fauna and Flora Preservation Society, Inc. (J.C. Walsh)

Felsberg, S.

Fisheries Association of Newfoundland and Labrador Limited

Fisheries Council of British Columbia

Fisheries Council of Canada

Fur Council of Canada

Fur Institute of Canada

Geistdoerfer, A.

Gourlay, L.

Government of Newfoundland and Labrador, Department of Fisheries

Grand Council of the Crees (of Quebec)

Greenpeace International (V. Bøe)

Greenpeace – Toronto (D. McDermott)

Greenpeace – U.K.

Henderson, G.

Henke, J.S.

Hicks, J.

Holman Hamlet Council (I. Aleekuk)

Holman Hunters and Trappers Association

Hyslop, J.

Indigenous Survival International

International Council of Environmental Law

International Council for the Exploration of the Sea

International Fund for Animal Welfare (Briefs prepared on its behalf by: D.M. Lavigne, M. Earle, S. Innes, G.A.J. Worthy, K.M. Kovacs, O.J. Schmitz, J.P. Hickie, S.J. Holt, R.D. Ryder, T. Regan, W.G. Watson, P. Singer, W.J. Jordan, M. Bruce)

International Seal Committee

Jeffords, Hon. J.M., House of Representatives, Congress of the United States

Karlsen Shipping Company Ltd.

Kilabuk, D.

Labelle, R.

Labrador Inuit Association

Lantos, Hon. T., House of Representatives, Congress of the United States

Lifeforce Foundation (P. Hamilton)

Lobster District 4B Working Group, (R.W. Jones)

Lobster District 5A and B Working Group (R.P. McClung)

Lobster District 7A, 7A1, 6A Working Group (R.E. Britten)

Local Development Committee of Fleur-de-Lys, (G.R. Walsh, M.P. Lewis)

Mackey, M.G.A.

Makivik Corporation

McCloskey, W.B.

McGrath, R.

Mississauga Animal Rights Society

Mowat, F.

Nettles, W.G.

New Brunswick Department of Fisheries

Newfoundland Department of Rural, Agricultural and Northern Development

Newfoundland Fishermen, Food and Allied Workers Union, Local 1252

Newfoundland and Labrador Federation of Municipalities (W. Dixon)

Newfoundland and Labrador Wildlife Federation (R. Bouzan)

Newfoundland Shipowner's Association

Newfoundlanders Against the Seal Hunt (M. Pumphrey)

Nova Scotia Department of Fisheries

Pauktuutit (Inuit Women's Association)

Prince Edward Island Department of Fisheries and Labour

Prince Rupert Fishermen's Cooperative Association

Rompkey, Hon. W., Member of Parliament, Grand Falls – White Bay – Labrador

Rowsell, H.C.

Royal Norwegian Ministry of Fisheries (T. Øritsland)

Royal Society for the Prevention of Cruelty to Animals

Rushton, D.

St. John's Board of Trade

Scheffer, V.B.

Seafood Producers Association of Nova Scotia

Société Linnéene du Québec Inc. (M. Carbonneau, B. Gauthier)

Southern Shore Development Association

Southwest Arm Regional Development Association

Symmes, A.

Terhune, J.M.

Tompkins, S.

Tungavik Federation of Nunavut

Union européenne contre l'emploi abusif des animaux

United Church of Canada

University of Victoria Animal Rights Society

Veevee, P.

Wenzel, G.W.

Wilderness Society of Newfoundland and Labrador

Woodcock, G.

World Society for the Protection of Animals (T.H. Scott)

World Wildlife Fund – Canada (M. Humel)

World Wildlife Fund/International Union for the Conservation of Nature and Natural Resources

3. Witnesses at Hearings of the Royal Commission

Amagoalik, J., Inuit Tapirisat of Canada

Amory, C., Fund for Animals

Andersen, C., Labrador Inuit Association

Andersen, T., Labrador Inuit Association

Andersen, W., Labrador Inuit Association

Angohiatuk, S., Sr.

Aningmiuq, C.

Arngak, C., Mayor of Kangiqsujuaq

Atagootak, S., Baffin Regional Hunters and Trappers Committee

Barker, A., Bonavista South Development Association

Barry, Hon. L., Leader of the Opposition, Province of Newfoundland and Labrador

Beckett, B., St. John's Board of Trade

Bekale, J., Indigenous Survival International

Billard, A., Eastern Fishermen's Federation

Boddington, C., for Congressman Tom Lantos

Bøe, V., Greenpeace International

Boudreau, P.

Bourque, J., Fur Institute of Canada

Bowen, W.D., Dept. of Fisheries and Oceans, Canada

Brokenshire, J.

Brown, M., Labrador Inuit Association

Brown, S., Canadian Federation of Humane Societies

Bruce, M., International Fund for Animal Welfare

Bulmer, R.W., Fisheries Council of Canada

Cashin, R., Newfoundland Fishermen, Food and Allied Workers Union

Chapman, B.W., Fisheries Association of Newfoundland and Labrador Ltd.

Coon, T., Indigenous Survival International

Corey, R.

Cormier, D., Association des chasseurs de phoque des Iles-de-la-Madeleine

Cournoyea, Hon. N.J., Minister of Renewable Resources, Govt. of Northwest Territories

Creed, L., Prince Edward Island Dept. of Fisheries

Currey, J.E.

Delaney, D., Association des chasseurs de phoque des Iles-de-la-Madeleine

Dicker, G., Labrador Inuit Association

Dupras, G.

Eetunga, T., Spence Bay Hunters and Trappers Association

Elias, A., Holman Hunters and Trappers Association

Emond, P.

Ernerk, P., Keewatin Inuit Association

Etooangat, A.

Evyagotailak, J.A., Coppermine Hunters and Trappers Association

Farmer, P., Eastern Fishermen's Federation

Flewelling, P., Dept. of Fisheries and Oceans

Franklin, J.N.

Geistdoerfer, A.

Gilday, C., Indigenous Survival International

Glover, M., Greenpeace – U.K.

Gourlay, L.

Grandy, J., Humane Society of the United States

Hamilton, P.E., Lifeforce Foundation

Hawley, J.B.

Hazel, S., Canadian Wildlife Federation

Henderson, G.

Henke, J.S.

Herscovici, A.

Holt, S.J., International Fund for Animal Welfare

Hughes, T.I., Committee on Seals and Sealing

Hunter, M., Fisheries Council of British Columbia

Hunter, P., Labrador Inuit Association

Hyde, P., Canadians for the Abolition of the Seal Hunt

Imiq, J.

Inaksajuk, S., Pelly Bay Hunters and Trappers Association

Jararuse, W., Labrador Inuit Association

Johannsen, Hon. L.E., Minister, Greenland Homerule Government

Johnson, M.

Jordan, W.J. People's Trust for Endangered Species

Kalleo, W., Labrador Inuit Association

Kataloyak, S.

Kaunaq, J., Keewatin Wildlife Federation

Keeyootak, P., Baffin Regional Inuit Association

Kilabuk, E.

Knelson, L., for Congresswoman B. Boxer

Kojak, A., Labrador Inuit Association

Kominsky, R., Fur Council of Canada

Konana, B., Gjoa Haven Hunters and Trappers Association

Koonoloosie, L.

K'ujaukitsoq, U., for hunters organization and community of Thule

Kupeuna, J., Kitikmeot Inuit Association

Labelle, R.

Lane, W., Labrador Inuit Association

Lavigne, D.M., on behalf of International Fund for Animal Welfare

Lewis, J.E., Atlantic Marine Wildlife Tours Ltd.

Lewis, M.P., Local Development Committee of Fleur-de-Lys

Livingston, J., Fur Council of Canada

MacKay, B.K., Animal Protection Institute

Mackey, M.G.A.

Maniapik, J., Mayor of Pangnirtung

May, A.W., Dept. of Fisheries and Oceans, Canada

McCloskey, W.B.

McDermott, D., Greenpeace Canada

McKay, B., Greenpeace International

Merkuratsuk, J., Labrador Inuit Association

Mike, J.

Miousse, A., Association des chasseurs de phoque des Iles-de-la-Madeleine

Moore, P.A., Greenpeace International

Moreland, R.

Mosdell, W.

Moses, T., Grand Council of the Crees (of Quebec)

Moss-Davies, J., Inuit Women's Association

Nahwegahbow, D., Indigenous Survival International

Nappaluk, L., Coop manager, Kanigiqsujuaq

Nappaluk, N.

Nettles, W.G.

Okituk, P., Makivik Corporation

Omingmak, D.

Onalik, W., Labrador Inuit Association

O'Neil, L., Member of Parliament, Cape Breton Highlands – Canso

Øritsland, T., Royal Norwegian Ministry of Fisheries

Ormrod, S.A., Royal Society for the Prevention of Cruelty to Animals

Paniloo, P., Member of NWT Legislative Assembly for Baffin Central

Penn, A., Grand Council of the Crees (of Quebec)

Puddister, A., Newfoundland Shipowners Association

Pudloo, J.

Pudloo, K.

Pumphrey, M., Newfoundlanders Against the Seal Hunt

Qarpik, P., Baffin Regional Hunters and Trappers Committee

Qissiq, J.

Quine, J.P., Canadian Veterinary Medical Association

Regan, T., International Fund for Animal Welfare

Renaud, R., Association des chasseurs de phoque des Iles-de-la-Madeleine

Rideout, Hon. T., Minister of Fisheries, Govt. of Newfoundland and Labrador

Rompkey, Hon. W., Member of Parliament, Grand Falls – White Bay – Labrador

Rowsell, H.C., Committee on Seals and Sealing

Rushton, D.

Ryder, R.D., International Fund for Animal Welfare

Sakiagak, M.

Scott, R.F., International Union for the Conservation of Nature and Natural Resources

Scott, T.H., World Society for the Protection of Animals

Seymour-Rouse, E.F., Eurogroup for Animal Welfare

Simpson, L., Dept. of Economic Development, NWT

Sikora, R.I., Canadians for the Abolition of the Seal Hunt

Simard, B.

Small, H.

Small, M., Canadian Sealers Association

Smith, K., Consumers' Association of Canada

Snow, D., Wilderness Society of Newfoundland and Labrador

Stirling, R., Seafood Producers Association of Nova Scotia

Sumner, W., Canadian Federation of Humane Societies

Symmes, A.

Tatty, R., Keewatin Wildlife Federation

Tatum, J., University of Victoria Animal Rights Society

Thomas, R., Canadian Society for the Prevention of Cruelty to Animals

Tompkins, S.

Tooktoshina, C., Labrador Inuit Association

Varin, H., Association des biologistes du Québec

Veda, L., Greenpeace – U.K.

Veevee, P.

Walsh, G.R., Local Development Committee of Fleur-de-Lys

Walsh, J.C., Fauna and Flora Preservation Society Inc.

Warren, G., Newfoundland Dept. of Rural, Agricultural and Northern Development

Watson, P.F., International Sea Shepherd Conservation Society

Watson, W., on behalf of International Fund for Animal Welfare

Wenzel, G.W.

Whelan, R.F.

Whitman, G.A., Hudson's Bay Co.

Winter, J.

4. Expert Assistance

Anderson, R.M., Imperial College for Science and Technology, London

Anderson, S., Sea Mammal Research Unit, Cambridge

Bakkala, R.G., Northwest and Alaska Fisheries Center, Seattle

Beck, B., Bedford Institute of Oceanography, Dartmouth, N.S.

Beddington, J., Marine Resources Assessment Group, Imperial College of Science and Technology, London

Beverton, R.J.H., UWIST, Cardiff

Braham, H.W., National Marine Mammal Laboratory, Seattle

Brodie, P.F., Bedford Institute of Oceanography, Dartmouth, N.S.

Bigg, M.A., Pacific Biological Station, Nanaimo, B.C.

Bonner, N., British Antarctic Survey, Cambridge

Bowen, W.D., Bedford Institute of Oceanography, Dartmouth, N.S.

Butterworth, D.S., University of Cape Town, South Africa

Calambodikidis, J., Cascadia Research Collective, Olumpia

Cowan, I. McT., University of British Columbia, Vancouver

Cushing, D.H., Lowestoft, U.K.

David, J.H.M., Sea Fisheries Institute, Marine Mammal Laboratory, Cape Town

Davis, R.A., LGL Ltd., King City, Ont.

Eberhardt, L., Pacific Northwest Laboratories, Richland, Wash.

Finley, K.J., LGL Ltd., Sidney, B.C.

Fowler, C.W., National Marine Mammal Laboratory, Seattle

Goodman, D., Department of Fisheries and Oceans, Ottawa

Harvey, J.T., Oregon State University, Newport, Oregon

Harwood, J., Sea Mammal Research Unit, Cambridge

Hoek, W., Arctic Biological Station, Ste-Anne-de-Bellevue, Que.

Holdgate, M.W., Department of the Environment, U.K.

Holt, S.J., Rye, East Sussex, U.K.

Horwood, J., Fisheries Laboratory, Lowestoft, U.K.

Hughes, T.I., Committee on Seals and Sealing, Newmarket, Ont.

Jotham, N.R., Canadian Wildlife Service, Ottawa, Ont.

Kapel, F., Grønlands Fiskeriundersogelser, Charlottenlund, Denmark

Langdon, S.J., University of Alaska, Anchorage

Lavigne, D.M., University of Guelph, Ont.

Laws, R.M., British Antarctic Survey, Cambridge

Lindquist, A., Food and Agriculture Organization of the United Nations, Rome

Lockyer, C., Sea Mammal Research Unit, Cambidge

MacKay, B.K., Animal Protection Institute, Toronto

Mansfield, A.W., Arctic Biological Station, Ste-Anne-de-Bellevue, Que.

Mate, B.R., Oregon State University, Newport, Oregon

McClelland, G., Department of Fisheries and Oceans, Halifax

Ni, I., Department of Fisheries and Oceans, St. John's, Nfld.

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6. Technical Reports of the Royal Commission

These reports have been deposited with the Headquarters Library, Dept. of Fisheries and Oceans, Ottawa, and with the Pinniped Bibliography, Dept. of Zoology, University of Guelph, Ontario.

1. Cooke, J.G., A.W. Trites, and P.A. Larkin. 1986. A review of the population dynamics of the northwest Atlantic harp seal (*Phoca groenlandica*).

2. Northridge, S. 1986. Impact on fish stocks.

3. Northridge, S. 1986. Report on damage by seals to fishing gear in Canadian waters.

4. Templeman, W. 1986. Transmission of nematode parasites from seals to commercial fish.

5. George, R.E. 1986. Estimation of costs of fish processors in Newfoundland and Nova Scotia attributable to *Pseudoterranova decipiens*.

6. Canadian Gallup Poll Limited. 1986. A survey of public attitudes in six countries to seals and sealing.

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8. Osberg, L. 1986. Policies for adjusting to a decline of the sealing industry: the Norwegian experience.

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12. Market and Industry Analysts. 1986. A study on the world market opportunities for Canadian seal products.

13. Gardner Pinfold Consulting Economists Ltd. 1986. Alternative employment options for those dependent directly or indirectly on sealing and the seal industry in Atlantic Canada.

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16. Gardner Pinfold Consulting Economists Ltd. 1986. A chronology of the Canadian response to actions by the European Community to ban the importation of seal products, 1964–1984.

17. Ryan, S. 1986. A historical overview of Canadian/Newfoundland/world sealing and the part this industry played in the development of the Atlantic Canadian/Newfoundland economy.

18. Worl, R. 1986. Sociocultural values of Clyde River Inuit: summary.

19. Hill, R.H. 1986. The social and cultural impacts of the seal utilization process in Newfoundland.

20. Williamson, H.A. 1986. Sealing in Labrador.

21. Compendium of observer reports concerning humaneness of the Canadian seal hunt.

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1. Sealers on the ice at the Front (circa 1920s).
   Provincial Archives of Newfoundland and Labrador.

2. Ringed seal.
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Chapter 3

1. Stretching sealskins (Northwest Territories).
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2. Hooded seal and blueback pup.
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1. The *Rainbow Warrior* in the Gulf.
   R. Greendale.

2. Adult harp seal and whitecoats.
   R. Greendale.

3. Grey seals.
   F. Bruemmer.

4. Atlantic whitecoat hunt.
   F. Bruemmer.

5. Inuit skinning bearded seal.
   Arctic Biological Station, Ste-Anne-de-Bellevue.

Chapter 6

1. Harbour seal.
   F. Bruemmer.

2. Northern fur seals.
   F. Bruemmer.

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1. Send-off of the sealing fleet.
   Provincial Archives of Newfoundland and Labrador.

2. Discharging seals from *SS Eagle*.
   Provincial Archives of Newfoundland and Labrador.

Chapter 13

1. Igloo at night (circa 1960).
   SSC – Photo Centre Library – ASC.

2. Conditioning sealskin by chewing it (1951).
   W. Doucette / Public Archives of Canada / PA-145968.

3. Seal hunter and sled.
   SSC – Photo Centre Library – ASC.

4. Naalak Nappaaluk (seal hunter) with Charlie Arngak.
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5. Inuit hunting camp (circa 1940).
   Public Archives of Canada / PA-42047.

6. Inuit hunter and catch.
   Arctic Biological Station, Ste-Anne-de-Bellevue.

7. Cleaning sealskins.
   SSC – Photo Centre Library – ASC.

Chapter 14

1. Sealing vessel near the Front.
   Public Archives of Canada / PA 128771.

2. Deblubbering sealskins, St. John's (circa 1920).
   Provincial Archives of Newfoundland and Labrador.

Chapter 15

1. Discharging sealskins, St. John's.
   Atlantic Guardian / Public Archives of Canada /PA 145967.

2. Crew's quarters on sealing vessel.
   Provincial Archives of Newfoundland and Labrador.

3. "Copying" at the Front.
   R. Greendale.

4. Landsman sealer, Magdalen Islands.
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Chapter 17

1. Seal watching.
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